DAMAGE BOOK

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SCIENCE TODAY AND TOMORROW

NICHOLSON AND WATSON

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Preface

THOUGH MEN OF SCIENCE USUALLY SHUN SPECULATION, they do not always refrain from indicating the potentialities of their work. I have seized on their prophecies and developed them in ways which, I hope, will not be deemed too extravagant. Indeed, I have found it necessary to temper some of their fantasies, this because an extensive acquaintance with the work of practical engineers has taught me what may and may not be realized in a future not too remote. My excuse for predicting as well as attempting to elucidate, lies in the growing interest that the public displays in the social implications of science. The task of a vulgarizer of science is no longer confined to mere elementary exposition of principles and procedures. He must indicate, as best he can, what effects new discoveries and inventions are likely to have on individual and community life. Indeed, a whole literature on what is called 'the impact of science on society' has been produced within the last decade.

My indebtedness to the many distinguished physicists, biologists, chemists, and engineers on whose writings I have drawn is evident enough. Special acknowledgement to them in this place seems unnecessary because it is made in the chapters themselves.

W.K.

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I. A Star Explodes

SPEEDING ON ITS WAY TO THE EARTH AT THE RATE OF 186,000 miles a second, a ray of light tells us of a stupendous catastrophe that occurred in the constellation Hercules 1300 years ago. A star burst asunder. While mailed knights were arming for one crusade after another, while monarchies rose and fell, while Scandinavian, Portuguese, Spanish and Italian navigators were making their great voyages of discovery, the light of that explosion was travelling towards us.

Now that it has arrived, science is in a better position than it ever was to understand the message. If planets revolved around that distant sun, if among them there were worlds on which oceans rolled and intelligent creatures strove to understand themselves and the vast universe about them, they have been destroyed in a mercifully swift, blinding, all-consuming flash. We can form no conception of the violence of the outburst, even though we behold it. An explosion of a mass of nitro-glycerine as big as the earth would be like the burning of a match in comparison —a snail-like performance.

Human eyes have never witnessed catastrophes as colossal as those signalled by these sudden glares. Insignificant blurs so faint that the unaided eye cannot see them change to luminaries of the first magnitude. Thus in a few days the new star in Hercules increased in brightness a hundred thousand times. Only Sirius, Vega, Capella, Arcturus, Rigel, Procyon, Altair, and Betelgeuse, the most brilliant fixed stars, ultimately exceeded it in brilliance.

Novae, or new stars, the astronomers call these sudden apparitions. It is a bad name, suggesting that orbs blaze forth where there were none before. Usually there is a faint spot of light on a photograph made ten, twenty, or thirty years previously to tell the story of a body that had pursued the even tenor of its stellar way for millions and millions of years, only to flare up suddenly and startlingly so that even unaided terrestial eyes can see it. Even when the photographic record gives no indication of a luminary destined some day to explode—Nova Aurigae, Nova Persei, and Nova Cygni are cases in point—there is little reason to talk of 'new stars'. Orbs are not created in the twinkling of an eye.

As a class novae are the brightest stars in our system—twenty thousand times brighter on an average than the sun. 'Could we look back upon our system from some immense distance from which all save the brightest stars had melted into an unresolved blur,' says Hubble, 'we should still see the novae as they flash out, shine for a while, and then fade away from sight. We actually see such flashes in Andromeda, a stellar system much like our Milky Way.' If most outbursts are faint, it is not because they are duller than that which has appeared in Hercules but because they are so far away.

The most famous of all novae was that discovered in November 1572 by Tycho Brahe, then twenty-six years old, in the constellation Cassiopeia. He dared not trust his own eyes. Read his account:

Raising my eyes as usual, during one of my walks, to the well-known vault of heaven, I observed with indescribable astonishment near the zenith in Cassiopeia a radiant fixed star of a magnitude never before seen. In my amazement I doubted the evidence of my senses. However, to convince myself that it was no illusion and to have the testimony of others, I summoned my assistants from the observatory and inquired of them and of all the country people that passed if they also saw the star that had thus suddenly burst forth.

Tycho's star rivalled the planet Venus in brilliancy and was visible at noontide. Never in historic times has there been another nova like it. Changing from white to red and then again to white, it faded out of sight by March 1574. Somewhere in Cassiopeia it still gleams faintly, but what star it is in that constellation is not known. With the coarse instruments of the time it was impossible to indicate positions with great accuracy.

To Tycho the star was a portent, which he likened to the halting of the sun at the command of Joshua and to the luminary that the Magi followed at the birth of Christ. Kepler held similar views about the naked-eye nova that he beheld in 1604. To him, the star of Bethlehem was a nova.

What is the cause of these outbursts? Astronomers have been asking themselves the question for centuries. The more that is discovered, the more puzzling does

it seem. No hypothesis thus far advanced is entirely satisfactory. According to some, we behold the consequences of a grazing collision of two stars. They coalesce to form a new ball of incandescent vapour.

Mathematicians sharpen their pencils and estimate the chances of such an encounter. Once in a million years, the answer reads. Wrong, comment the observers. Novae are too frequent in the universe at large. Besides, there was the curious case of Nova Pictoris, which split and revealed a dark space between the sundered parts. It may not have been a typical nova, this Nova Pictoris, but if the collision hypothesis is valid, that dark space should not have appeared.

Developing a suggestion made by Prof Monck, the German astronomer Dr Seeliger made interesting deductions which were in high favour for years. There is dark stuff scattered through space—cosmic dust, vapours, who knows what? It appears on photographs when a bright star shines near or through dark matter. Indeed, on some pictures a star seems to have ploughed a lane through it. Nova Pictoris, which brightened and faded several times—other novae have done the same—may have encountered now a dense and now a rare mass of such dark matter as it plunged on.

We know that a meteor flares up as it rushes through our atmosphere. Here we see what can happen when a huge star swims into a dark nebula. Moreover, novae are associated with nebulae. Here and there is a ring of glowing matter, a planetary nebula,

and in the centre a glowing mass. Are these rings, perhaps, the wrecks of ancient novae?

Plausible as Seeliger's theory may seem, astronomers reject it. By friction in the supposed passage of a star through a nebula heat is generated much too slowly to account for an almost instantaneous, flash-like eruption.

Astrophysicists are now inclined to attribute stellar explosions to sheer instability. For some unknown reason a star collapses. The outer layers are blown off and flung out into space at speeds of hundreds, and even thousands, of miles a second. Collapse of the core that remains involves shrinking—a purely gravitational effect. Light, heat, waves of energy are literally squeezed out. But where are the facts that make it possible to estimate whether such changes occur often enough to explain all cases? We indulge in mere scientific speculation. There is no other way as yet.

What we know about novae has been learned largely since the spectroscope was introduced in the last century. It is the function of that instrument—the essential element is a prism—to split light into its constituent colours. What we have is a rainbow, a spectrum in the form of a ribbon-like strip. Each element glows with its characteristic set of coloured bands and lines, and each set of bands and lines appears in a definite part of the spectrum. If a line or band shifts, a physicist knows that a star is moving towards or away from us, depending on the direction of the shift.

Just as a locomotive whistle howls up as it approaches and down as it recedes, so light howls up and down as the source travels towards or away from us; for light, like sound, has its pitch. By measuring these shifts, velocities can be computed. The spectroscope therefore reveals the elements in a star or mass of gas, their physical state and their movement. Stellar rainbows in the hands of Drs Wright and Lundmark, Dr Walter S. Adams of the Mount Wilson Observatory, and Donald A. Menzel and Miss Cecilia Payne of Harvard have made it possible to form a crude picture of what occurs when a star explodes.

We are asked to imagine a sun which has become unstable and which has hurled off its outer shell of hot gas. What remains shrinks by perhaps a few hundred miles, which is nothing compared with a diameter of a million miles and more, yet enough to cause such a rise in temperature that astronomers on the earth become aware of a blaze.

Like a swelling bubble the shell leaps outwardly with an ever-enlarging radius at a rate that may be 1000 miles a second and more. In a week the volume of the shell increases millions of times. It ought to cool by the mere act of expanding and radiating. Instead it glows almost as intensely as the star itself, though there is sometimes evidence of cooling.

At first the shell is opaque. All the radiation from the star at the centre must fight its way through. Electrons and ions dash about in riotous activity. Cosmic rays, gamma rays, X-rays, ultra violet rays

struggle with this opposition. At last they break through, but transformed. They are feebler. Once invisible and highly penetrating, they are now 'soft'. That is why they can be seen.

In this early stage, during which the brightness of the whole mass increases enormously, the glow is brilliant white or bluish-white. Later it turns orange or reddish. The spectrum tells the story of hydrogen, iron, calcium, titanium, chromium, silicon, and other familiar vapours heated until their dancing atoms emit characteristic waves of light. Similar metallic vapours appear on the sun. Towards the last the star turns greenish. In the later stages the once opaque shell becomes transparent, so that cosmic rays and other powerful rays penetrate easily enough. Luckily for us our own atmosphere blocks them.

Soon after the maximum brightness is attained the nova declines. In a few weeks it is but a weak reminder of its brief spectacular glory. Steadily it fades for months and years. Then it settles down as an ordinary star among millions in its part of the heaven. Sometimes there is a fitful pulsing of light—an indication that equilibrium has not yet been completely attained. It is a smaller but a brighter and hotter star that thus marks the end of an explosion.

Notice that in this picture of the rise and fall of a nova we refer to cosmic rays which pour out of the central star within the shell of gas and vapour. Have we here the origin of the mysterious radiation which Dr Millikan believes to be an intense but invisible

form of light? Dr W. Baade of the University of California and Dr F. Zwicky of the California Institute of Technology have suggested the possibility.

From a statistical study made at Harvard by Dr Bailey it seems that one or two novae reach naked-eye visibility every year, though few are actually discovered. In the same period at least ten attain the ninth magnitude. (Ptolemy, the first man to arrange the stars in the order of their brilliancy, called the brightest 'first-magnitude' stars and stars just visible to the naked eye 'sixth-magnitude' stars. A ninth-magnitude nova is one-sixteenth as bright as the faintest naked-eye stars.) Bailey concludes that in the course of a few million years there would be as many spent and broken-down novae in the sky as there are visible stars.

Every star has therefore been a nova in its time. Consider what this means in the light of modern astronomical photography. Billions of stars are now caught on plates. If these orbs represent but a tenth of the actual number that still await discovery, we prepare ourselves to think of novae as commonplace phenomena. It may even be that stars have been novae more than once.

A more recent statistical examination of novae has been made by Dr Conrad Lonnqvist of the Royal Observatory of the University of Lund, Sweden. According to his findings, the average star explodes and becomes a nova once in 400,000,000 years. Lonnqvist gives himself ample elbow-room when he deals with

such astronomical probabilities. His figures are admittedly wrong by a trifle of 300,000,000 years one way or the other. Three hundred million years! Time enough for mountains to be shaken and worn down, for seas to dry up, for radio-activity to become a mere tradition handed down from an almost mythical twentieth century and for the human race to throw off the last vestige of savagery.

If Bailey and Hubble are right, we naturally wonder what is to become of our own solar system. Our sun is a star which happens to have planets revolving around it. It has a photosphere, a kind of luminous shell or atmosphere of fiercely glowing gas that for ever conceals the core beneath. Tongues of red hydrogen leap up from that shell and sunspots whirl within it. Both testify to terrific forces at play.

The mere thought of what would happen if the sun should burst as that star in Hercules did 1300 years ago is enough to make one shudder. Nothing could survive an outburst of energy that would inundate the solar system. A glare that would strike us blind, a flood of radiation—cosmic, ultra-violet, electric—would pour out. In a few days the outwardly travelling shell of incandescent vapour would rush on the earth. Soon it would engulf Mars, Jupiter, and Saturn. There is even the probability that it would sweep out in an ever-widening sphere until it embraced Uranus, Neptune, and Pluto. Shells as vast have been observed.

All this would happen with a suddenness of which

we have no inkling. The first blast would be enough to blot out all life. The planets, as they swam in their orbits around the transformed sun, would be heated up like meteors. Once more they would become balls of vapour and mingle with that shell of death and destruction. In the end they would be dissipated like wraiths of smoke. Nothing would be left of a system which may be unique in all the wide expanse of the universe. Then, after months, and perhaps years, the sun would subside. It would be a smaller and more brilliant sun—a white star drifting in solitude through space.

Will cosmic history repeat itself? In other words, will some wandering star again sweep into our part of the heavens and by sheer gravitational attraction pull out of the new sun streamers of gas and then pass on? Such at least is the accepted theory of what happened billions of years ago, when there were as yet no planets. For out of the streamers the planets and their satellites were formed by a process of shrivelling and knotting.

Perhaps the cycle will be repeated. Perhaps the new sun, smaller but more brilliant, will again fall prey to a wanderer. Perhaps a new solar system and a new earth will be born. Perhaps there will be a new birth of life, with a bit of primeval protoplasm emerging from the sea to begin anew the old slow ascent that eventually leads to swaying trees, to animals that crawl and run and birds that cleave the air, and at last

to something like man who will gaze wonderingly at the heavens above and detect afar a flash that tells of a sun's destruction and of his own cyclic career.

II. The Sun: New Aspects

SOME 93,000,000 MILES DISTANT BLAZES THE SUN, A MINOR luminary among the hundreds of millions in the universe. As the nearest star, it is of extraordinary importance to the astrophysicist. Why is it hot? Why does it shine? How long has it glowed? Of what is it made? What is its temperature?

Astronomers have been asking these questions ever since there were medicine-men to preside over festivals held in the sun's honour and sacrifice animals to its glory and power. From decade to decade the answers are modified in the light of new discoveries. With the invention of the telescope, 'close-ups' and therefore accurate description and inference became possible. The sun proved to be not a homogeneous ball but something like an onion. There were layers of matter.

First comes the corona, stretching out perhaps 350,000 miles and so wondrously thin that during a total eclipse comets can pass through it without being retarded, and so strongly suggestive of auroral streamers that it must be electrical in its nature. Because of the brightness of our sky, only during the fleeting moments of a total solar eclipse is it seen. On the airless moon it would be otherwise. Perch yourself on a lunar crag. The weird corona would spread out like a halo every day. And behind the sun a black sky studded with stars would appear—stars that never twinkle.

Within the corona, hugging the outer rim of the sun, lies the chromosphere—a sea of crimson hydrogen 5000 miles deep, agitated by tempests compared with

which ours are as zephyrs. Red fangs leap out with a speed one hundred times that of a rifle-bullet for distances of 10,000 to 350,000 miles. 'Prominences', the astronomer calls them. Some are politely classed as 'quiescent' for no other reason than that they spread out mushroom-like, with stems that apparently run down into the photosphere, two layers down.

Not so long ago the red eruptions of the chromosphere were so many puzzles. Why should hydrogen be tossed up at all, considering the tremendous, inexorable pull of gravitation—more than twenty-seven times as great on the sun as on the earth? On this basis a 150-pound man would weigh two tons in the chromosphere; all the solar wrappings ought to be compressed into a layer less than a mile in thickness; an unsupported body, a mass of gas for example, would fall 450 feet in the first second, 400 miles in a minute, 230,000 miles in half an hour. Yet these prominences last sometimes for more than a month. What holds them up?

The astrophysicist supplies the answer. Radiation exerts pressure. 'With a sufficiently strong light one could knock a man down just as surely as with a jet of water from a fire-hose,' says Jeans. If we do not notice the pressure of light on the earth it is because it amounts to only 75,000 tons for the whole illuminated hemisphere. Within the sun the effect is far more formidable — enough to fling out great fantastic wraiths of hydrogen despite the pull of gravitation.

Within the scarlet chromosphere, and 1000 miles

thick, is the 'reversing layer', so called because of its effect on bright lines of the spectrum when seen under the right conditions. Deeper still lies the photosphere, a layer of incandescent cloud of unknown thickness—to us the real sun.

Galileo saw spots on the sun. That was almost the natural result of the invention of the telescope in 1608. Keen observer, shrewd reasoner that he was, he did not make the common mistake of regarding the spots as planets that stood out against the blazing background of the sun. 'Bourbonian stars', as the French called them? Nonsense. These black patches were on the very face of the sun. Galileo's explanation was not received with favour. Blemishes on that bright face, the very symbol of purity and perfection? It seemed like blasphemy.

Galileo, after all, was but a describer of what he saw. It took decades of patient observation to infer the utter dependence of the earth on the spots and this by carefully noting when they came and went. Schwabe, an indefatigable German, showed the way and impaired his eyesight in gathering statistics about them. For twenty years he watched and counted, noted the number of spots day after day, and at last announced that sunspot maxima occur on an average every 11·4 years. Ninety years of observation has enabled astronomers to make only a slight correction. The average period is now placed at 11·1 years.

This tireless watching of the spots by astronomers

brought forth the astonishing fact that the sun does not spin all in one piece, like a ball of white-hot metal. The greater the distance from the sun's equator, the slower is the rate of spin. At the solar equator it is 24·65 days; at latitude 35 degrees, 26·63 days; at the poles about 34 days. But the spots themselves rarely appear in high latitudes. They flank the equator between the fifth and fortieth parallels.

Thousands of drawings and photographs of the spots have been made. Always there is a central purplish patch—the 'umbra'. Fringing it is a texture of tossing plumes, lacy filaments—the penumbra. Look at any picture of the spot and you say at once: 'That's a hole.' Astronomers were once of the same opinion. But instead of revealing some awful inferno these 'holes' seem to conceal something. They are dark, and darkness means that they must have a temperature lower than that of the dazzling gas around them. Hold the burning end of a cigar against a brilliant electric arc and it looks black. So on the sun. The spots are incandescent for all their blackness, but cool compared with the glowing masses around them. A supposedly 'black' spot with a diameter of perhaps 50,000 miles is a hundred times brighter than the full moon.

No longer are the spots regarded as holes. There can be no question of their real nature. They are cyclones like those that lift roofs of houses in Kansas—spinning, elevated funnels of hot hydrogen, evidences of storms on a star that is itself one colossal storm.

'Small', an astronomer would call a spot that measures less than 8000 miles in diameter, and there have been some spots with diameters of 50,000. All are flaming tornadoes, vortices out of which fiercely glowing gases are tossed, into which the earth might be dropped without touching the sides. Kansas takes to the cyclone cellar when a tornado sweeps by and sucks wells dry. But what of a whirlwind as big as the whole earth—a whirlwind of leaping, flaming gas? Moreover, what of a whirlwind which is not only of this colossal size but which lasts for days, weeks, months?

Yet the physicist likens these fiercely glowing vortices of gas to refrigerators. When we think of cold we think of frost, snow, and ice. He thinks of differences in temperature. Freezing water has a temperature of 32 degrees Fahrenheit. The thermometer in the kitchen itself on a hot summer day may register 82 degrees. So the white-enamelled insulated box and coils give us a temperature drop of 50 degrees—a triumph of mechanical engineering.

Turn to the sun and see what happens. That spinning tornado which we call a spot sucks hot gases from the interior and cools them by expansion—exactly what happens in the coils of a refrigerator. But the temperature drop—2000 degrees! Such is the difference between the 6000 degrees absolute (10,000 degrees Fahrenheit) of the solar surface and the temperature of a spot.

When these solar tornadoes are at their height, compasses go wild; powerful earth currents are induced

that sometimes demoralize the telegraph services; auroras shimmer with unwonted brilliancy. These are clearly magnetic phenomena. So astrophysicists naturally looked for magnetic effects in the spots. It was long before they found them.

To the late Dr George E. Hale belongs the honour of proving that every sunspot is a huge magnet. He found that the polarities of a pair of spots are always opposed. Furthermore, if the eastern spot of a pair has a northward polarity, so will it be with the eastern spots of all other pairs in the northern solar hemisphere. In the southern hemisphere the corresponding spots will have a south-pole magnetic orientation. When a new cycle occurs the polarities are all reversed. Why this should be so, no one knows.

In forty observatories scattered over the world delicate magnets are suspended, each linked with the sun by invisible yet tangible bonds. Something besides light rushes across the chasm of 93,000,000 miles that separates sun and earth. Electrons, wrecked atoms called ions, whole molecules perhaps, are shot from the solar surface and from the spots. Fifty miles from the earth's surface the invisible stream is largely stopped by the atmosphere. And so the magnets in the observatories twitch or vibrate. 'Storms!' they seem to cry. But the storms are not of lashing wind and rain, but of electrons. At such times the aurora glows with more than its usual magnificence and compasses wobble.

Magnetic storms occur from two to five times a year

and last for about two days. When sunspots are big the disturbances are apt to be violent. For more than twenty-five years daily records have been kept at the forty observatories. If sunspots reappear in a cycle at twenty-seven-day intervals, as they often do, the observatory charts show a twenty-seven-day correspondence of earthly terrestrial magnetic disturbances. The correspondence is not exact, yet striking enough. Twenty-seven days happens to be the period of the sun's rotation. Yet the most that an authority on terrestrial magnetism will permit himself to say is that magnetic activity must be attributed to definite regions on the sun's surface and that there is an eleven-year cycle of magnetic disturbances just as there is an eleven-year cycle of sunspots.

So we look for causes. Imagine something like the revolving nozzle of a garden hose, a nozzle as big as the sun. It sprays electrons, ions, and perhaps other particles into space. The sprays fall in arcs like drops of water. In a day and a half the abyss is bridged. But a minute elapses between the first impact and the time the earth is completely enveloped by the magnetic storm. Only by some such mechanism is it possible to explain why the magnets in the forty observatories begin to vibrate almost as soon as a big spot appears.

Hardly had the eleven-year sunspot cycle been established—evidence of rhythm—when the attempt was made to correlate it with similarly recurring phenomena on the earth. This is the primrose path that leads either to astounding scientific congruences or to

a mild form of lunacy. It is possible to take any railway time-table and develop from the hours at which trains arrive or depart from a terminal a striking relationship between the appearance and disappearance of sunspots. There would be no difficulty in linking the increase in nervous indigestion with the rise of broadcasting or in showing that the spread of the cafeteria coincides with an appalling increase in the cancer death-rate.

Human life is a series of events, some of which recur periodically, such as birthdays, pay-days, harvest seasons, tennis-matches, and financial depressions. To superimpose one curve on another, both expressing rhythms; to show that the two agree; to deduce cause and effect in this manner—what is apparently more logical? So we find that not only have the mystics tried to discover whether our supposedly voluntary acts are really influenced by sunspots, but also the scientists themselves.

Back in 1875 Prof W. Stanley Jevons, one of the most distinguished of British economists, developed a theory of Sir William Herschel's that there is a relation between the sunspot cycle, weather, and crops. He wrote monograph after monograph to show that sunspots affected the price of grain and that they were even responsible for depressions.

In 1931 Inigo Jones, director of the Bureau of Seasonal Forecasting in Queensland, made out what seemed to be a strong case for the solar control of Australian weather. With much ingenuity he showed

that the sunspot cycle is caused by the movements of the planets, especially colossal Jupiter, which has a periodicity of 11·86 years, and that irregularities caused by Saturn, Uranus, and Neptune account for the accepted 11·1. His tables and curves indicate that every 164 years there is abnormal weather because of the conjunctions of planets and sunspots. The supporting evidence is almost overwhelming. Yet it is precisely the kind of evidence that astrologists adduce to prove that when certain planets are in conjunction it is well to stay at home and avoid assassination by a dark man with gleaming eyes.

And then there is Henri Mémery, who in 1932 brought out a treatise (*L'Influence Solaire et le Progrès de la Météorologie*) in which he advanced the theory that sunspots evince a tendency to increase and decrease at certain definite times of the year and that for fifty years there has been a clear relationship between the spottiness of the sun and abnormal rainfall and temperature. He bends figures and cycles so readily to his will that he finds no difficulty in proving that when there is a marked increase in sunspots there is a rise in the temperature in Southern France. His critics demand more exact statistical methods than he has employed.

We turn to Russia and we find Dr W. B. Schotakovitch, whose work has received the attention and the implied endorsement of so able a meteorologist as Dr H. H. Clayton. After studying the records from 1869 to 1920, Schotakovitch decided that many spots

mean much rain and that this excess rain is associated in some regions with increased evaporation. Since this happens to agree with the widely held view that during epochs of sunspot maximum the earth receives a greater amount of solar heat, we have this scheme: increased heat, increased evaporation, increased rainfall.

But the boldest of all these jugglers of statistics is Prof A. L. Tchijevsky, whose revelations were presented in 1927 before the American Meteorological Society. If anyone wants to link the crash of 1929 and all the subsequent misfortunes with sunspots, he will find all the evidence he wants in Tchijevsky's deductions and predictions. There was a sunspot maximum between 1927 and 1929; there were also pronounced psychic effects in previous maxima. Ergo, the world must look before the end of 1929 for events which will shake minds and affect progress. The prediction was right. But what of the logic? Is a theory true merely because it appears to work?

Tchijevsky undertook the herculean task of going back to the fifth century B.C. and correlating sunspots with 'gigantic mass insanity, elementary violence, epidemics of murders, the invention of demoniac forms of torturing and killing', not to mention wars, mass excitements, pilgrimages and religious movements. Attila, Mohammed, Joan of Arc, Napoleon, Richelieu, Gambetta and Lenin were most active and brilliant when sunspots were at their height, according to Tchijevsky.

The association of sunspots and rainfall was also the

lifework of Dr W. P. Köppen, who studied meteorological records for several hundred widely scattered stations. That there is some relation, accurate measurements of the sun's surface with the pyrheliometer seem to prove. It is clear enough that when sunspots are most numerous the sun is at its hottest. The effect is to stir up the earth's atmosphere, just as when the draughts of a stove are opened. There is increased evaporation, which means more clouds and therefore more rainstorms. The net result is that the earth is cooler when the sun is hottest, which is not so paradoxical as it seems, in the light of the explanation given. But an acid-proof case for the influence of sunspots on weather has still to be made out.

What lies below the photosphere, on which the magnetic spots drift, must always be mere conjecture. Who can hope to pierce 432,500 miles of gas (the radius of the sun) and discover what is at the core of a star more than 92,000,000 miles away? And yet the modern astrophysicist boldly attempts the feat because of the confidence that his knowledge of atoms and electrons has given him. In the revolutions and leapings of electrons in earthly atoms he reads the story of the sun. Once we revered Helmholtz and Kelvin as the final authorities on solar processes. Now we sit at the feet of Eddington and Jeans, physicists whose views on the activities of solar atoms and electrons have made it necessary for astronomers to change their conception of the sun.

If he can explain why the sun shines at all, the physicist can explain nearly everything. According to the easy reasoning of past centuries, the sun burned like a mass of fuel. A sun made of solid coal would last about 5000 years, by Lord Kelvin's reckoning. Could showers of meteors keep the fires burning? More calculations disposed of that supposition. A mass of meteors equal to that of the whole earth would hardly supply the solar furnace for a century. Besides, the necessary infall would double the sun's weight in 30,000,000 years and disarrange the whole solar system.

It was the German physicist Helmholtz who advanced an explanation satisfactory to modern astrophysicists. The sun is a mass of gas. It is contracting. But by how much? He applied his mathematical calipers and obtained 250 feet a year. Heat and light were being squeezed out of the sun.

Then and there a controversy sprang up between the physicists and the geologists. Lord Kelvin calculated that the shrinking process had begun not more than about 40,000,000 years ago, and Newcomb that it could not continue for more than an additional 7,000,000. The sun's span of life was therefore a matter of perhaps 47,000,000 years. The geologists protested and pointed out that some of the earth's rocks were 100,000,000 years old, and that the sun, which was at least as old as the earth, was far from being the blackened cinder it should be.

When the radio-active elements were discovered, the

case of the geologists was even stronger. It takes uranium about 1,300,000,000 years to break down spontaneously into various elements (one of them is radium) before it is reduced to lead. It must have taken the earth still longer to cool and form rocks. Even the geologists had been much too unimaginative in estimating the age of the ball on which we live.

When the electron theory of matter was formulated the real source of the sun's great energy was discovered. 'We started to explore the inside of a star,' said Eddington; 'we soon found ourselves exploring the inside of an atom.' By which he meant that atomic energy accounts for the sun's radiance.

The forces that tie an atom together are tremendous. Yet outer electrons can be torn away, whereupon an atom becomes an 'ion'. It takes energy to strip an atom. The sun has a surface temperature of at least 10,000 degrees Fahrenheit. At the centre, the temperature may be 40,000,000 degrees. A speck of iron heated at Chicago to the calculated temperature of the sun's interior would radiate enough heat to blast all life within a radius of 1000 miles.

A temperature of 40,000,000 degrees means that molecules move fast. At ordinary room temperatures air-molecules rush about with a speed of 500 yards a second; at 40,000,000 degrees they would dash about at more than 60 miles a second. In gravitational contraction we have the energy that raises the temperature of the stars until they glow internally with a terrific, inconceivable heat. And in this heat we have the force

that disrupts atoms into their individual electrons, brings about the transmutation of elements, and releases more energy. Now we are ready to contemplate Eddington's sensational picture of the sun's interior:

Dishevelled atoms tear along at 100 miles a second, their normal array of electrons being torn from them in the scrimmage. The lost electrons are speeding one hundred times faster to find new resting-places. Let us follow the progress of one of them. There is almost a collision as an electron approaches an atomic nucleus, but putting on speed it sweeps round in a sharp curve. Sometimes there is a sideslip at the curve, but the electron goes on with increased or reduced energy. After a thousand narrow shaves, all happening within a thousand-millionth of a second, the hectic career is ended by a worse sideslip than usual. The electron is fairly caught and attached to an atom. But scarcely has it taken up its place when an X-ray bursts into the atom. Sucking up the energy of the ray, the electron darts off again on its next adventure.

Jeans carries the process further: not only are atoms being reduced to their individual protons and electrons, as Eddington so vividly pictures, but the protons and electrons are themselves being annihilated. And the proof of this annihilation is to be found in the sun's fierce light and heat. Or, as Jeans puts it: 'The sun is destroying its substance in order that we

may live. . . . The atoms in the sun are in effect bottles of energy spilled throughout the universe in the form of light and heat.' Yet so enormous is the sun's supply and so great is the energy content of each bottle that even after having blazed for at least 7 or 8,000,000,000 years—Jeans's estimate of the sun's age—there is still enough left for many more billions of years to come. The geologists now have all the time they demand to explain how the earth acquired its rocks, seas, and continents.

It cannot be denied that there is some guessing about these billions of years, but it is guessing with a solid foundation, based as it is on the relation between the sun's luminosity and its weight. The heavier a star, the brighter will it be. But the ratio between weight and luminosity is not what might be supposed. If the sun were only half as massive as it is, it would radiate not one-half as much light and heat, but one-eighth. Similarly, if it were twice as heavy as it is, it would shine not twice but eight times as brightly. About 2,000,000,000 years ago the sun had 1·00013 times its present weight. When the earth was born, some 3,000,000,000 years ago, the sun must have been much as it is now. To the modern astrophysicist the sun is still young, though to the Victorians it was guttering to its end.

It is because of the relation of mass to brightness that both Jeans and Eddington agree on the sun's age. Go back, say 7,600,000,000 years, and the sun becomes impossibly heavy—about one hundred times as heavy

as it is now. An age of 7 or 8,000,000,000 years gives just the right weight and brightness.

But how does Jeans know what is the right brightness? By comparing the sun with other stars of the same type. It turns out that each square inch of the sun's surface radiates about fifty horse-power, which is generated by the annihilation of matter at the rate of about a twentieth of an ounce in a century. For the sun as a whole this insignificant amount adds up to more than 4,000,000 tons a second. Tomorrow the sun will weigh 360,000,000,000 tons less than it does today. Yet it is so huge that it will shine for at least 15,000,000,000 years longer.

Until Jeans and Eddington gave us these new views, the sun was supposed to be a tremendous glowing ball of gas. But Jeans showed that a gaseous sun would either collapse or explode. He imagines the core to be liquid. Only the outer wrappings are gaseous in the true sense. At the core, he holds, there are superactive atoms much heavier than uranium or radium. We have ninety-two kinds of elements on the earth; if Jeans is right, there may be more kinds deep in the solar core. A few short-lived elements heavier than uranium (our earthly ninety-second) have been produced in the laboratory.

Since the sun is radiating itself away and losing 360,000,000,000 tons every day, its gravitational clutch on the earth must be slackening. Jeans has calculated that we are spiralling from the sun at the rate of little more than a yard in a century. In 1,000,000,000 years

we shall be 101,530,000 instead of 92,300,000 miles away. By that time the sun will have lost 6 per cent. of its present heat through radiation, and its energy-producing capacity will have been reduced by 20 per cent. The terrestrial temperature will be 54 degrees Fahrenheit lower than it is now, and the earth will be reduced to an icy ball swimming through space. If they have not evaporated long before then, the oceans will be frozen masses.

Will man have perished? He has the power of creating an artificial environment for himself. He knows how to heat his homes and his factories. More than glacial cold is needed to exterminate him. But, as the earth drifts away with the passing of the centuries, a temperature that was once glacial and tolerable with the aid of science will approach the absolute zero of interstellar space.

The curtain falls when the atmosphere is precipitated first in blizzards of carbon dioxide and finally in a downpour of liquid air. No inventive ingenuity can stave off death. After having stumbled into a universe that was never destined for life, man will be blotted out by forces that were hostile to him from the beginning of time and over which he triumphed for a brief hour, 'leaving the universe,' in Jeans's words, 'as though he had never been.'

III. Birth and Death of the Moon

IN THE REMOTE PAST, THE EARTH WAS UNDOUBTEDLY A perfect sphere of gas. The late Sir George Darwin, son of the great Charles, threw himself back mathematically hundreds of millions of years, and so did Henri Poincaré. They beheld in their equations a spectacle the like of which was never presented elsewhere in the solar system—beheld the gaseous earth spinning faster and faster on its axis so that it ceased to be a perfect sphere and assumed the shape of a spheroid. In their mathematical minds' eyes they could see millions of years slipping by and the earth spinning still more dizzily. Additional equations revealed the earth, under this accelerating rotation, changing from a spheroid into something shaped like an egg.

The egg-shaped mass of gas cooled, became a liquid, and continued to spin faster and faster. Darwin saw a temporary collapse, causing the egg to assume the shape of a pear. More millions of years elapsed. The stalk end of the pear developed a bulb and the waist of the stalk became thinner and thinner.

So fast was the earth now spinning that the day was only three hours long, a velocity sixteen times faster than that of a rifle-bullet. Tides raised by the sun aided centrifugal force in distorting the earth. The liquid pear, coated by this time with a crust some 35 miles thick, could not withstand the combination. A cataclysm of terrific magnitude occurred. Five thousand cubic miles of matter constituting the bulb were wrenched loose. In that stupendous convulsion the moon was born. Some astronomers profess to see

in the basin now filled by the Pacific Ocean the scar of that planetary catastrophe.

No other satellite had an origin like this. To an astronomer on Mars the earth and the moon appear as they really are—a double planet of marvellous beauty. Physicists have thrown the moon on their mathematical scales. It weighs 73 trillion tons—one-eightieth of the earth's mass. Of all satellites in the solar system none approaches the moon in size and mass.

The moon was not forthwith hurled 239,000 miles into space, whence it now shines down. At first it revolved around the earth at grazing distance. For whole geological epochs its destiny trembled in the balance. Had the speed of rotation been but a fraction of a minute faster than it was the moon would have crashed back upon the earth. But the complicated mechanism that governs planets and satellites decreed that the moon should slow down so that the month exceeded the three-hour day by a second or two. Thus it became possible for a lunar tidal wave to creep ahead of the moon. The tide applied its frictional brakes, and 54,000,000 years ago the moon began very slowly to spiral away. Moreover, the earth's day lengthened, and so did the moon's. The lunar astronomical day is now a terrestrial month.

In considering these past changes in the length of the lunar day, it must be remembered that the earth was a liquid mass. It had what physicists call a natural period of vibration. By rhythmic shaking a wave could be raised, which depended on the size and shape of

the earth for its period. The fluid or semi-fluid earth in that remote time was subject to just such oscillations. They had a natural period of two hours. But every two hours the sun was also producing two tidal bulges on opposite sides of the earth. Tap a pendulum at just the right moment and its swing can be lengthened. A similar effect was produced on the earth. The oscillations of liquid matter were like the swings of a pendulum; the sun raised bulges at just the right moment to agree with the swings and increase them. No liquid planet could withstand the combination. A bulge broke off. Thus the moon was born.

The moon began to creep away from the earth as soon as it was born. At first the day and the month were of equal length—four or five hours. As the moon receded, both lengthened, but the month more rapidly.

Ultimately the moon will retrace its course. Rigid and frozen as it is, nevertheless it will be distorted the nearer it comes. There is now a bulge in the direction of the earth, a bulge that goes back to a time when the moon was plastic.

When the moon comes within two-fifths of its present distance from the earth the bulge will be subjected to tremendous pulling strains. Astronomers will witness exciting events. Lunar mountains will topple. There will be great avalanches. On the earth cracks will open in which cities will be engulfed. Terrible earthquakes will shake the planet.

It is easy to imagine the terror of mankind. The

earth is doomed as a habitable place. In the sky the moon is poised, not the moon that we see—a mere half-crown held at arm's length—but an awe-inspiring moon covering a twentieth of the sky. Huge rocks are attracted by the earth, some of them a mile in diameter. Luckily they do not rain down on Europe or America, but travel around the earth in orbits of their own. For some centuries astronomers watch the process. Then the inevitable downpour deluges the earth.

Mountains crack on the moon and their fragments, irresistibly drawn to the earth, beat down relentlessly on all that men cherish. The sky is aflame with meteorites, heated to incandescence by friction with our atmosphere. The rocks and meteorites that are not wholly consumed fall down, bury themselves with loud explosions, and heat the surrounding country thousands of degrees. Forests burn up. Oceans boil.

Astronomers have seen the end coming for a millennium and longer. The human race long ago sank its hatreds, its selfish thefts of territory, its economic jealousies, in a fine co-operative effort to save itself from extinction. In vain. Vast subterranean refuges dug beneath the North and South Poles shelter a few hundred thousand who manage to escape the terrific pelting from the awful moon above. What are their chances in a steaming ocean licking away at the Great Ice Barrier of the South or the glaciers, floes, and icebergs of the North?

The end comes when the moon is rent asunder

20,000 miles distant from the earth. The bombardment is more terrific than ever, and the heat engendered by the collision of fragments with the earth is such that nothing can withstand it. The sky is ablaze with white-hot meteorites. In the subterranean refuges the last men have long since gasped out their lives. Newspapers on Venus announce the sensational news: 'MOON CRASHES INTO EARTH AT LAST!' Yes, at last. For the Venusians have been awaiting the end for centuries.

Around the earth revolves a ring of meteorites—all that is left of the moon. And the earth drifts on, a blackened ball on which oceans once heaved, air made the azure sky a delight to the eye, green trees rustled in the wind, and man struggled up the long path of evolution that led from the first bit of animated protoplasm to something like divine intelligence. Who knows but the old planetary ruin may bloom again? The cosmos has its cycles.

IV. Life in the Solar System

SOME BILLIONS OF YEARS AGO A COLOSSAL STAR SWAM INTO our part of the heavens. It drifted near our sun and by the sheer gravitational power of its mass pulled out of the sun long streamers of gas. The wanderer passed on. The streamers shrivelled into globes that became our planets. So runs the prevailing theory of the solar system's origin.

The odds are a hundred million to one against such an encounter. Hence Eddington remarks: 'The solar system is not a typical product of the development of a star; it is not even a common variety of development; it is a freak.'

There are many reasons for supposing that the solar system may have been created thus. Jeans has pointed out that 'the long filament pulled out of the sun is likely to have been richest in matter in its middle parts, these parts having been pulled out when the second star was nearest and its gravitational pull the strongest'. String the planets in a line but preserve their relative distances from one another, draw a line around them, and you have a cigar. In the middle of the cigar are Jupiter and Saturn, the two largest planets.

If we pursue the inquiry in Eddington's frame of mind we find that each one of the planets in the system is in its turn a freak. No two have identical sizes and masses or identical lengths of day and night, or identical atmospheres, or axes tilted at identical angles. Despite their common origin the planets differ far more than do the children of the same family.

It is because of the uniqueness of the solar system

and the uniqueness of the earth that life is a precarious, exciting cosmic adventure. It literally hangs by a thread. Tilt the axis of the earth so that it assumes a new angle to the ecliptic (the great circle of the celestial sphere which is the apparent orbit of the sun, so called because eclipses can occur only when the moon is on or near this line), lengthen or shorten the day or year materially, rob the atmosphere of its oxygen and water vapour, change the globular mass and therefore the attraction of gravitation, or greatly increase or decrease the distance from the sun, and every plant and animal perishes.

A combination of a dozen known conditions and perhaps many more that are not known made it possible for the first bit of protoplasmic ooze to become animate, reproduce itself, and, what is more, evolve through the sponge, fish, reptile, bird, and mammal into Buddha, Leonardo, and Beethoven. The many essentials of life are so remarkably interrelated that it seems as if being alive cannot be fortuitous, as if it is the very purpose of nature to experiment with a thousand million stars to produce one little world for the creation of protoplasm capable of evolving into a myriad organic forms.

All this is borne in upon us by the recent discoveries that have been made about the atmospheres of the major planets. The astrophysicist with the aid of his spectroscope transports himself through millions of miles to worlds incredibly terrifying and beautiful. Here, for example, are Drs Slipher, Adel, and Wildt

in different parts of America and Europe piecing together the story of Jupiter, Saturn, and Uranus, and here Drs Walter S. Adams and Theodore Dunham of Mount Wilson revealing new facts about Venus.

Spectroscopes were known fifty years ago. Why did we have to wait so long for these new discoveries? Because new techniques were needed rather than new instruments.

Sunlight may be likened to a noise made by hundreds of instruments. Just as we cannot tell merely by hearing a noise what instruments are involved, so we cannot tell merely by looking at sunlight or starlight what elements are producing it. What we need is a filter to sift out one kind of light from another. By studying the different kinds of light thus sorted it is possible to identify the sources.

With the modern spectroscope the primary colours are broken up into thousands of coloured bands and lines, which appear in definite places in the spectrum and thus make it possible not only to identify the elements that glow in a star but also to deduce much about their state. When, therefore, the astrophysicist sees a certain yellow line he says at once: 'Sodium.' If he sees red ones he says: 'Hydrogen.' So with oxygen, nitrogen, strontium — all the ninety-two elements.

In the case of the planets the tell-tale bands and lines are found chiefly in the visible red and invisible infra-red portions of the spectrum. When a chemical was found for making photographic emulsions respond to

invisible red rays it was as if scales had fallen from the mind's eye.

But even if chemistry thus came to the aid of the astrophysicist, the task of discovering the conditions on a planet so remote that even in the most powerful telescope it is no larger than a sixpenny piece was not easy. The lines and coloured bands of these planetary rainbows or spectra are faint. There are probably some that are still invisible, for all the improvements made in emulsions.

Ever since there were spectroscopes strange orange bands had been noted in the rainbow-like spectra of Jupiter and Saturn. About 1905 Dr V. M. Slipher of the late Percival Lowell's Flagstaff Observatory found that the bands of Uranus and Neptune were even stronger and that there were others in Jupiter and Saturn so faint that no one had seen them before. After studying Slipher's photographs Prof R. Wildt of Göttingen, Germany, published in 1932 the conclusion that the strong bands probably came from ammonia and methane. But certainty was wanted.

What the physicist does in this case is to bring the planets to the laboratory. That is, he creates the conditions which are supposed to prevail on them. Enter his sanctum sanctorum. There are no planets in miniature, no surroundings that suggest the study of a medieval astrologer. Steel bottles of ammonia, methane, and hydrogen, a long tube in which an atmosphere of these gases is imprisoned at the right pressure, a spectograph to record the bands and lines into which a beam

of light that shines through the tubes is broken—that is all.

Lines that are faint in the spectra of the actual planets now stand out prominently, besides others that are not seen at all—particularly in the infra-red region. It is as if we had found the missing segments of an incomplete jig-saw puzzle and fitted them into the gaps that awaited them. With the aid of such apparatus Dr Dunham of Mount Wilson filled in the details of the rather coarse picture obtained by direct spectroscopic study of the planets and reached the conclusion that Jupiter and Saturn have atmospheres of hydrogen and ammonia gas. In the same way Drs Slipher and Adel have proved that the faint bands of Jupiter and Saturn are produced by methane or natural gas.

'So this is Jupiter,' you say to the physicist in charge, who probably wears a linen smock and looks more like the alert foreman of a machine shop than the picturesque juggler of worlds that you had imagined him to be.

'No, only its probable atmosphere,' is his reply. 'Nobody ever saw Jupiter or Saturn. Only its clouds.'

Such work does much to dispel the notion that Jupiter is still red-hot after a separation from the sun that occurred perhaps 5,000,000,000 years ago. Red heat implies a temperature so high that ammonia and methane would be decomposed. Their bands and lines would not appear in the rainbows that have been studied.

So, two new worlds are visualized. They have cores like the earth's—heavy, dense, solid lumps of nickel-iron. Outside is a thick layer of ice under high pressure; above that a highly compressed atmosphere with much hydrogen and ammonia and methane. Why the high pressure? Because of the known masses of the two planets. The clutch of gravitation upon them is more powerful than upon the earth. On Jupiter a man would find it difficult to lift his arm because of its weight. The earth lost most of its hydrogen long ago because of its small mass. Jupiter and Saturn retain their allotments because of their greater mass.

We need measurements of temperature to piece out the story. Drs Pettit and Nicholson of Mount Wilson supply them. The two direct on the planets a sensitive thermo-couple of their own invention. It is one of the most delicate devices at the disposal of the modern physicist—so sensitive that it can measure a rise or fall of three hundred-thousandths of a degree. And how simple! The heat of a star billions of miles away falls on infinitesimal strips of bismuth and tin alloy. A feeble current is set up. By measuring the current the temperature is determined. The operative portion of the instrument weighs less than a pinhead.

What are the findings of Pettit and Nicholson? Cold, bitter cold. Minus 220 degrees Fahrenheit for Jupiter and minus 280 for Saturn. The cold is so intense that ammonia freezes solid. Dunham, Slipher, and Wildt independently reach the conclusion that the two great planets are wrapped in clouds of am-

monia crystals. So thick are the clouds that it is impossible to see deep down to the surface, where the methane must be particularly rich. Light a match on that surface, whatever it may be, and the atmosphere would catch fire—become a roaring furnace if there were any oxygen. In fact, there would be an explosion, an instantaneous chemical combination that would yield carbon dioxide and water.

The ammonia clouds scud over the surfaces of the two planets and thus testify to terrific hurricanes travelling at 400 to 600 miles an hour on Saturn and at least 250 on Jupiter. Why these terrific blasts? No one knows. Our own winds are the result of the sun's heat. But at the distance of Jupiter and Saturn the sun is so remote that it can hardly warm chilly hydrogen and solid ammonia crystals. Here we have the chief argument of those who still believe that Jupiter and Saturn are red-hot.

The same method of spectroscopic analysis and the same reliance on artificial atmospheres in tubes in the hands of Drs Adams and Dunham have made it clear that the air of Venus is composed largely of carbon dioxide—the gas which froths in beer and bubbles in ginger-ale and which is as necessary for the support of terrestrial life as oxygen. Through some mysterious alchemy, of which we know hardly the rudiments, light acting upon the carbon dioxide of our atmosphere produces green plants, and with them starches and sugars. Given green vegetation, it follows that there

must be water and the necessary mineral salts to support it, with oxygen as an exhaled by-product. And plants in their turn suggest the great drama of evolution.

We turn to Mars. Not so long ago physicists differed about its temperature. Dr Coblentz of the Bureau of Standards settled all doubts with the aid of a marvellously sensitive thermo-couple only one two-hundredths of an inch in diameter. With that instrument he measured the heat received not from the planet as a whole but from particular regions. For the South Pole in summer 15 to 50 degrees Fahrenheit were the readings; for the South Temperate Zone at the same season, 65 to 75 degrees; for the tropics at noon, 65 to 85 degrees; for the North Temperate Zone in winter, 30 to 60 degrees. The planet proved to be warmer than the sceptics contended. Probably the Martian equator is bitter cold at night, but no colder than New York at its wintry worst.

But what of the Martian atmosphere? Water vapour and oxygen are there—both prerequisites of life. Astronomical doubters once believed that the Martian white polar caps were not snow but solidified carbon dioxide. Now it is certain that the caps are snow or hoarfrost that melts in the spring and summer and inevitably gives rise to water vapour. Dr Wright has photographed Mars at Mount Wilson with light of different colours and discovered yellow, watery clouds floating at a height of 15,000 feet.

On the other hand, Prof Henry Norris Russell of

Princeton thinks that the red areas of Mars may be otherwise interpreted. He bids us consider the oxygen that the earth carried with it from the sun when the great creative catastrophe occurred. Half of the original amount is gone. We see it everywhere in the form of iron ore (mere rust), iron-bearing red clays, and red sandstone. Iron combines avidly with oxygen. Ultimately all our oxygen will be thus chemically removed from the atmosphere. If man is not to die gasping for breath he will have to liberate oxygen some day from the ores, clays, and rocks in which it is being imprisoned. Prof Russell sees in Martian red deserts deposits of rusty ore. Nevertheless, vines may crawl over the ground, and even the kind of vegetation which Dr Coblentz suggests may flourish on Mars may conceal the rust in the warmer season.

With all this evidence there is little doubt that Mars can support some simple form of life. The planet is a spent world, drying up and slowly dying of senility. The dark-green areas that spread in summer and turn an ochreous red in autumn are probably areas of vegetation. But of what kind? No one knows. Coblentz thinks it may be accounted for ' by the presence of tuft-forming grasses such as grow on high prairies, the tussock grasses of Peru and Patagonia, and especially the mosses and lichens which grow in Arctic regions.'

When we turn to the other planets we face enigmas. Mercury is so near the sun that lead would

melt on its surface and water flash into steam. Uranus and Pluto are so far off that the sun must appear like a brilliant star. Days that are no brighter than our late twilight, seasons measured by years, cold that is as intense as that which prevails on Jupiter and Saturn conjure up a vision of terrifying barrenness.

So it seems as if only the earth is capable of supporting the higher forms of life—the one freakish world in a freakish solar system. The astronomer who yawns whenever he reads anything that deals with the possibility of life on other planets rejoices in these facts. 'A minor crustal phenomenon at the surface of a planet,' Shapley calls life. To Jeans it may be 'a mere accidental and possibly quite unimportant by-product of natural processes, which have some other and more stupendous end in view.' Human beings, anthropoid apes, birds, lower animals, bacteria—they play no part in astrophysics.

If the canals of Mars are to be interpreted as engineering works, the door is opened wide for speculation. The polar caps, though obviously natural phenomena, might be regarded as artificial by romanticists. Since it would not always be possible to distinguish between the works of nature and of intelligent beings, the relentlessness of present reasoning vanishes. Hence the perfect satisfaction with which the watchers of the skies turn from Mars—the only planet besides the earth that can be considered as the abode of a low form of life—to Jupiter and Saturn with their clouds of stifling ammonia and their

tornadoes of inflammable methane, to broiling Mercury, and to the bitter cold of Uranus, Neptune, and Pluto. Life as we know it never had a chance on them.

But that observation of Eddington's about the freakishness of the solar system sticks in the mind. Can it be that nature creates a thousand million stars and causes them to radiate their substance away in order to produce a cinder or two with just the right relation to a central sun, with just the right atmosphere and chemical conditions for the support of life? Have we here justification for man's conceit—his deep conviction that he is the very king-pin of the universe?

V. Rocketing through Space

IT WAS THE NOVELIST J.-H. ROSNY, AÎNÉ, WHO COINED THE word 'astronautics'. The sum of 5000 francs is annually awarded by the Société Astronomique de France on behalf of its donors, Robert Esnault-Pelterie and André Hirsch, for the most meritorious original contribution to the advancement of astronautics. The prize has been won by Frenchmen, Germans, and Americans. Astronautics! The science and art of voyaging from star to star. How utterly puerile and inconsequential seem the transatlantic flights of our boldest aviators compared with the stirring implications of that single word!

To leave the earth and rush through space with velocities never before achieved by man; to see with one's own eyes the features of that other face of the moon which is for ever turned away from the earth; to settle once and for all by personal inspection the real nature of those mysterious 'canals' of Mars which Lowell thought were irrigation-ditches dug on a planetary scale by a race of intelligent beings struggling to stave off extinction by husbanding the water of the melting polar snows; to pierce the veil of Venus, impenetrable to earthly telescopes, and to discover what lies behind it—surely the technical imagination is capable of no more magnificent flight.

A recital of past 'impossibilities', which, somehow, have come to pass, does not prove that men can leave the earth and voyage through the solar system. It becomes necessary to examine the obstacles that the astronaut must surmount, to design a mechanism which

may be regarded as an artificial meteor, controlled in its flight and inhabited by passengers, and to forecast the responses of the human organism to an environment in which the word 'weight' ceases to have any meaning.

What is it that prevents us from voyaging to the moon and the more distant planets? Primarily the earth's gravitation manifested by weight. To escape into space we must overcome our weight and the weight of our vehicle—overwhelm one force with another.

Every boy who has ever pitched a baseball has acquired an elementary knowledge of the earth's power. He throws the ball up into the air. It takes a measurable time to return, and during part of that time it actually defies gravitation. He throws it again—this time with more force than before and therefore still higher. It takes longer to return. Thus the fact is driven home that the more force with which the ball is hurled the higher it will fly and the longer it will take to return. Clearly, if there were a pitching machine powerful enough it would be theoretically possible to throw a ball any distance—even to the moon.

This naturally leads to a calculation of the force required to overcome gravitation so that a projectile would never return to the earth. By applying Newton's law of gravitational attraction it develops that a body must have a velocity of about seven miles a second to escape the pull of the earth. Seven miles a second! And the fastest bullet has a muzzle-velocity

of less that 3000 feet a second! Undaunted by the discouragingly small amount of energy that can be released by igniting an explosive powder, Jules Verne nevertheless shoots men into space in his novel *From the Earth to the Moon*, shoots them in a luxuriously furnished shell from a colossal cannon buried in the earth. Verne evidently had the assistance of an expert in ballistics in imparting to his tale all the illusion of scientific reality that accompanies the presentation of easily grasped mathematical calculations. When voyages into the cosmos began to be discussed by abler men than Verne, it was discovered that for all their plausibility his cannon and his enormous charge of powder were much too feeble. Indeed, it may be doubted whether his projectile, half villa and half shell, would ever have left the cannon at all. The truth is that with no powder known and with no cannon that can be constructed can man convey himself across the awful chasm that separates him even from the neighbourly moon.

And so we turn to other vehicles than colossal shells. Airplanes? They must be dismissed at once. Interplanetary space is airless, and air is as necessary to a flying machine as water to a transatlantic liner. The whole machine is supported by air, the engine must breathe oxygen like a human being, and the propeller must screw its way through air. Zeppelins? They must be discarded for similar reasons. We need an engine that can propel itself in a vacuum. Only the rocket meets the condition, for the rocket is propelled

merely by the back-pressure of the burning gases that stream rearward from it at high velocity.

Just why the rocket should be thus propelled is not difficult to understand. One of Newton's laws of motion tells us that action and reaction are equal and opposite in direction. A stone wall pushes you as hard as you push it. Fire a shotgun and your shoulder feels the recoil. What drives the rocket is recoil. A rocket literally kicks itself on its way, whether or not that way is filled with air. An engineer classes a rocket as a reaction engine, and the physicist accepts it as the only type that can possibly conquer the abyss that separates planet from planet.

It might be supposed from an uncritical reading of the newspapers that only in our day has the rocket been considered as a means of interplanetary communication. Jules Verne admitted that he had been inspired by no less a person than Cyrano de Bergerac, who once wrote a tale of an escape from New Canada in a vessel which was driven by rockets to the moon. Newton naturally pointed out the possibilities of journeying through space on the rocket principle as a corollary of his action-and-reaction law. Achille Eyraud, an obscure contemporary of Verne's, proposed the use of a rocket for the exploration of space, and this in 1865, the very year in which *From the Earth to the Moon* appeared. In our own generation at least a score of novelists have voyaged in imagination from planet to planet in rockets. What is more to the point, a whole school of physicists and engineers

has busied itself with astronautics, with the result that a formidable, highly mathematical literature has accumulated which considers the rocket under all conceivable conditions, from the moment it leaves the earth in a deafening roar to the moment when it drifts through space a mere speck in the solar system and yet part of it.

Scientific study of the rocket's cosmic possibilities begins in 1881 with Hermann Ganswindt, whose unfortunate name only added to the ridicule that his studies brought upon him. Now we have Franz von Hoefft, Prof K. E. Ziolkowsky, Dr G. Tichoff, Prof Herman Oberth, Franz A. Ulinski, Dr Walter Hohmann, Prof R. H. Goddard, André Bing, Robert Esnault-Pelterie, and others. It would be idle to pretend that the mathematical and experimental researches of these men are all of equal merit. On the other hand the monographs of Oberth, Hohmann, Goddard, Esnault-Pelterie and Valier have certainly lifted the interplanetary rocket ship out of the limbo of such lunacies as the perpetual-motion machine and squaring the circle. Indeed, von Opel's startling exhibition of a rocket automobile's speed on the Avru's racetrack near Berlin in 1928 did much to gain respect for his friend Valier's bold imaginary wanderings through the solar system. Books on rocket ships are popular in Germany. Oberth's prize-winning *Wege zur Raumschiffahrt* has passed through several editions. A whole periodical, *Die Rakete*, is devoted to the publication of recondite articles on the construction of ships that kick

themselves from star to star and on the physics, physiology, and psychology of cosmic voyages. There is or was a *Reichsdeutscher Verein für Raumschiffahrt* in Breslau. Another in Vienna, organized by von Hoefft, is extinct. There was even a First International Exposition for Space Navigation organized in 1927 by Prof Fedrow.

Although he was not the first in the field, it was undoubtedly Prof R. H. Goddard of Clark University, Worcester, Massachusetts, who gave the thoughts and plans of astronauts purpose and direction. His primary object is to explore the upper reaches of the atmosphere with the aid of instruments which are virtually artificial sense-organs and which automatically write down their impressions of temperature, humidity, wind-velocity, electrical discharges, and the intensity of sunlight. His calculations show that it is possible to convey a pound of magnesium-flash powder to the surface of the moon and to watch its explosion from the earth through a telescope. Unlike most of those who preceded and followed him, he has conducted experiments which have given the whole cause of astronautics an enormous intellectual impulse because they show how the rocket's efficiency as a reaction engine may be greatly increased. By properly shaping the nozzle of a rocket Goddard succeeded in attaining a speed of 8000 feet a second with a commercial smokeless powder. More recent experiments indicate that 12,000 feet a second is now possible. Contrast this with the 2500 feet a second with which a bullet leaves

the muzzle of a rifle and it is evident that Goddard's rockets are probably the fastest projectiles ever built by man. Incidentally, an efficiency of 64 per cent. was obtained, which is more than twice as high as that of the best Diesel engine.

A rocket is accelerated as it rushes on partly because it loses weight as its propellant is dissipated. It is the final velocity that gives the physicist pause. Prof Goddard has calculated that to deposit a kilogram (2·2 pounds) of flash powder on the moon at least 600 kilograms of propellant are required. Hence he reached the conclusion that useless chambers must be automatically discarded to save weight. The amount of the propellant required is thus brought within reason. Nearly all astronauts therefore design their rocket ships so that sections that have served their purpose are shed. Some physicists also recommend that the propellant be fired in cartridges, one by one, on the machine-gun principle, the empty cartridges being automatically ejected.

But 8000 or even 12,000 feet a second is not enough for aerial navigation. We must seek propellants far more powerful than nitrocellulose compounds. Goddard, Oberth, and others agree that an explosive gas composed of oxygen and hydrogen contains the requisite energy. This complicates the problem inasmuch as pumps must be provided and alloys must be devised which will not become brittle in contact with intensely cold liquid gases. Both Goddard and Oberth have experimented with propellants of this nature. It has

been found that 43·5 pounds of such a mixture can send a pound of weight out of the earth's gravitational influence. The exact composition of these propellants is not known. Oberth has experimented with a mixture of oxygen and an inflammable gas or liquid such as hydrogen, gasolene, alcohol, and street gas. With correctly designed nozzles and some means of casting off useless load, both Goddard and Oberth believe it possible to reach the moon and even Mars. The late Max Valier was convinced that no propellant known to man can drive a rocket beyond the moon. Robert Esnault-Pelterie, a brilliant engineer with a vast experience as a designer of airplanes behind him, believes that only atomic energy will enable an astronaut to visit another planet and return to the earth. Goddard has shown what can be accomplished with correctly designed nozzles, and Oberth has been especially ingenious in reducing loads. It is significant that these two physicists are convinced that some combination of oxygen and hydrogen is sufficient for the astronaut's purpose.

It must not be supposed that the astronauts are all for building a space-ship as huge as an ocean liner without preliminary experimenting. Following Prof Goddard's example they advocate the construction of small, unmanned rockets which can be sent to heights not yet reached by kites and sounding balloons. The next step is to hit the moon and explode a pound or two of magnesium-flash powder in accordance with Prof Goddard's plan. What follows then is a matter

of dispute. Some would build a craft which would be a hybrid airplane and rocket and with which long-distance experimental flights in the earth's atmosphere could be made. A flight from Berlin to New York would occupy less than a forenoon. Oberth, on the other hand, is convinced that the high-speed rocket can never be combined with the airplane. By progressive steps he would arrive at a rocket which would be used for experiment—a rocket which would attain a height of perhaps 350 miles and in which a voyage around the earth at the rate of 24,000 miles an hour would become a pleasant excursion between breakfast and luncheon.

In order to reduce the charge of propellant to practical limits and facilitate a return to the earth, Oberth has boldly suggested that the moon be used as a kind of filling-station by rocket ships bound for Mars and Venus. After refuelling, a new start can be made with a velocity of less than two miles a second, because of the lesser attraction of the moon. Inasmuch as the moon is airless and its surface is blisteringly hot for one half of the month and at nearly absolute zero for the other half, its utilization as a filling-station is a technical feat of no mean order. But the astronauts think of everything. Suits are to be worn which can be inflated with compressed air supplied from tank-knapsacks. Huge reservoirs for propellants and storehouses for provisions are to be erected, and this very easily because tons can be handled on the moon as efficiently as pounds on the earth. The astronauts even

suggest that artificial satellites be created which can be made to revolve around the earth and Venus at predetermined distances. These satellites, they declare, can be constructed in fifteen or twenty years and will facilitate studies for ever impossible with terrestrial telescopes. The asteroids between Mars and Jupiter become so many natural way-stations on journeys to Jupiter.

Although it is intended to reach the moon in just about the time that it takes a fast liner to steam from New York to Southampton, a rocket is no more complicated than a ship. Indeed, the reaction motors (mere chambers from which gas is ejected at high velocity) are much simpler than the turbines of a ship. It is not especially difficult to construct a rocket weighing 300 to 1000 tons in sections which are dropped one by one after their usefulness is over. Stability is the first essential. This means that the rocket must not tumble. To keep its pointed head in the line of flight gyroscopes must be installed—small, rapidly spinning flywheels which resist any force that tends to disturb their plane of rotation. Rudders are useless in a vacuum. Side-nozzles may therefore be provided through which gases may be made to stream when the course is to be changed, although gyroscopes give better control.

How can the captain of a rocket ship chart his course? The position and apparent size of the earth will tell him all he need know. He must be able to measure its diameter accurately. If the earth appears

too large or too small at a given instant the starting velocity was correspondingly too low or too high. Should the earth be angularly situated too far this way or that way relative to two stars, the ship is off the course by a measurable arc.

Let it not be supposed that if the space-ship were as highly developed as the airplane now is, a jaded millionaire has only to say: 'I'm off for Mars tomorrow,' and dart off into the vast universe as casually as he flies for Bermuda. When the ship shall leave is determined not so much by the astronautical company that owns her as by the positions of the planets. And she leaves not within the hour or minute but precisely on the second. Time-tables are compiled by astronomers. Mars and the earth must be relatively near each other if fuel is to be saved and the length of the outward and inward voyages is not to be measured by years.

If a rocket ship can travel seven miles a second, and Mars in opposition is only 36,000,000 miles distant, why should a voyage out and back last more than a few weeks? Because we follow not a straight line but the courses prescribed by the planets themselves. Jules Verne estimates correctly that it will take 97 hours, 13 minutes, and 27 seconds to reach the moon if the initial velocity is 12,000 yards a second. Hitting the moon is somewhat like hitting a bird on the wing. The marksman must aim ahead of his target so that it will meet the bullet in just the calculated instant. But there is no reliance on instinct when we deal with 260,000 miles in the case of the moon and 36,000,000

with Mars at its nearest. Only a good mathematician can determine when the rocket should start and what direction it should take. He must allow for the earth's motion and its rotation around its axis and for the motion of his planetary target. Mars must be met, as it were, by appointment at a definite point in the universe.

Nothing travels in a straight line in the cosmos. Of necessity our rocket ship follows a curve. The astronauts have decided that it were best for it to follow some elliptical orbit of its own for a given period. In a word, its motors are stopped at the proper time and it becomes an artificial planet, a member of the solar system which revolves around the sun in a definite period. When Mars looms up in its own orbit, the rocket motors are started again and the ship heads for its destination.

It is no easy matter to select the ellipse that brings the space-ship nearest Mars in the shortest time. All the principles of celestial mechanics must be applied. Allowances must also be made for variations in the speed and in changes of direction of the ship. The nozzle-velocity of the escaping gases must be known. Hohmann and Valier have tabulated all the ellipses that can possibly be considered by astronauts of the future. You consult the table and find that Mars can be most economically reached by entering an ellipse which should carry the ship around the sun in somewhat less than two years or, more accurately, in 531 days. The outward voyage will usually take 260½ days

if the ellipse pursued touches the orbits of both Mars and the earth. Only one half the ellipse need be described to reach the planet. Ellipses might be selected which would shorten the journey to 171 days, but the cost in energy would probably be greater than the astronautical company would care to pay.

Man is a creature who has adapted himself to a peculiar environment. If he is to survive in interstellar space or in deep water, he must carry an artificial duplicate of that environment with him. Because the submarine engineers have already solved his problem for him it will not be difficult for the astronaut to supply passengers and crew with air and to dispose of exhalations.

But air is not enough. The cabins must be heated. Let a rocket travel from the earth to Mars and that side which is turned to the sun becomes scorchingly hot while the other side is at nearly absolute zero. Oberth lines the sunny side of his rocket with black paper or silk, which absorbs the heat and re-radiates it within the cabins. He has also thought of concentrating the sun's rays with concave mirrors if ordinary absorption and re-radiation are insufficient. Other physicists would construct the rocket on the vacuum-bottle principle. The exhausted space between the double walls would neither absorb nor radiate much heat, so that some artificial heat would be necessary for warmth.

It will be more difficult to guard against the violence of the start. When an automobile lurches forward, you

feel yourself suddenly pressed against the back of your seat. In a rocket the sensation continues because the speed increases steadily. Not mere speed but acceleration is dangerous. The space-ship starts from a state of rest and in eight minutes is rushing along at the rate of seven miles a second, assuming that the acceleration is 25 metres the first second, 50 the next, 75 the third, and so on. Acceleration manifests itself as pressure and an actual increase in weight so long as it lasts. It is as if a titan weighing half a ton were kneeling on your chest and flattening every square inch of you. The loose silver in your pocket buries itself in the flesh. Your chest barely manages to heave as you gasp for air. Try to lift your arm. It takes an effort so mighty that the perspiration trickles into your eyes. You manage to remove from your waistcoat pocket a gold pencil that presses painfully against you. Because your grasp is none too firm the pencil is torn from you and flung against the bulkhead behind you.

Even the most optimistic astronauts concede that the physiological effect of rapid acceleration is a danger with which they must reckon. Oberth believes that internal injuries may be sustained and that normal nervous reactions may be interrupted. The fluid in the spinal column will certainly be affected and likewise the liquid in the labyrinth of the middle ear—that spirit-level which governs our sense of equilibrium. On the other hand it may be argued that no one knows what forces the human organism can withstand. Pilots in looping airplanes survive centrifugal forces that

ought to tear their arms and legs from their sockets and their heads from their shoulders, and acrobats drop into nets under accelerations that spell certain injury on paper. The more cautious astronauts would conduct experiments with monkeys to measure the forces to which the body can safely be subjected.

It is evident that during the first terrible moments of a flight to another world you do not sit at your ease. In fact you do not sit at all. You are slung in a heavily cushioned hammock; for only in a horizontal position can you possibly withstand the agonizing pressure of acceleration. Woe to him who is on his feet when the ship lurches forward. He is hurled against the stern bulkhead of his compartment, flattened out, perhaps killed. All the astronauts advocate the lowest possible starting speeds. Oberth first burns a mixture of alcohol and oxygen and in a minute passes to oxygen and hydrogen. It is questionable whether it will ever be possible to overcome an objection which is inherent in the very principle of the rocket.

When the ship is out of the gravitational influence of the earth, by which we mean that it cannot fall back, you must adjust yourself to an entirely new set of physical circumstances. If but a moment before you were tortured by high pressure, you are now struck with terror because you feel no pressure at all. You weigh nothing, because the earth is too far away to attract you sensibly, although its influence theoretically never ceases. You clutch your hammock in desperation. The ship seems to be falling. To be sure it is

'alling, but only in the sense that every planetary body 'alls—as the moon, for example, constantly falls owards the earth but is constrained to describe a :losed curve in so doing.

The truth is that the ship is now a part of the solar ;ystem, a miniature world which requires no motor to lrive it and which revolves around the sun in accordınce with the laws of solar gravitational attraction in a lefinite year of its own. The officers appear to reassure 'ou. You unfasten yourself and step out. You find that 'ou can stand in mid-air. Nothing falls in a terrestrial ense. Release your grip from the cup that is in your ıand and it simply remains where it is. A match flung ıside travels on until it is stopped by a bulkhead, to 'emain there. Chairs and tables are screwed down so hat they may not assume strange positions when they ıave been accidentally tilted. Everywhere there are 'opes and straps. You learn quickly enough that it is ›est to use them and progress hand over hand from ›ne spot to another. If the ship has magnetic floors you vear steel-soled shoes, so that you may walk about in ı seemly earthly fashion. There is no need of a bed. 'ou slip your arms and legs into straps and go to sleep. 'illows? They are useless, since your head has no veight.

Voyage thus for two years and the muscles must ıtrophy. The passenger who returns to earth finds it ıard to accustom himself to active work and normal ›ressures. Some of the astronauts, Oberth among hem, have taken the trouble to devise cabins which

can be spun, so that the centrifugal force generated will constitute a substitute for the gravitation or weight-effect to which the human organism is accustomed.

Eating and drinking become somewhat precarious. Pouring wine out of a bottle is impossible. The wine simply remains where it is. The glass must be broken and removed like a cracked eggshell, so that the wine may be served as a ball—the shape which it assumes. Or the bottle may be whirled around so that the wine is driven out by centrifugal force. Even then it must be served as a globular lump. Soup appears not in a tureen but as a globe that floats in from the kitchen, followed by meats and sauces. Each course must be pursued by hungry passengers. When they swallow they run the risk of committing suicide. Meat and drink naturally gravitate into the intestinal tract, aided by the peristaltic action of the stomach. In interstellar space food is as apt to run down the windpipe as down the gullet. To be drowned by a cup of tea is not an impossibility on a rocket ship.

The astronauts apply the absence of any marked terrestrial gravitational pull very practically. If you are clad in a suit inflated with air at the right pressure and equipped with an oxygen-tank, there is no reason why you should not pass through an airlock and thus into space. You do not fall away from the ship. You cannot be left behind, for you move in your orbit at precisely the same speed as the ship. You place yourself relatively to the ship just as you would place a

chair relatively to a table in your library, knowing that the positions are fixed. The recoil of a pistol-shot will propel you to and from the ship, if you must move about in space. We understand now why Oberth constructs his rocket so that the bow can be separated from the body. After the fastenings are unscrewed, a slight push is enough to drive the bow forward. A long cable makes it possible to pull the bow back and bolt it in place.

Clad in your air-filled suit you step out on an observation platform of the Oberth ship and look about you. An overwhelming sense of loneliness. There is nothing for the eye to 'lean' upon—nothing but the ship that seems woefully small, although it is as large as a yacht. A new welkin is unfolded. There is no night, no day. The motionless sun blazes relentlessly in a brownish-black canopy—a star that seems like a gigantic ball of white-hot metal. You blot out the sun with your hand. And around the sun appears the weird, pearly corona seen on earth only during total eclipses. Despite the glare of that fervid disk the stars are visible everywhere. They shine with the hard, steady cruel light of so many remote electric arcs. You realize how much beauty the atmosphere imparts to the earth—that dust-and-moisture-laden atmosphere which scatters the sun's rays and gives the sky its azure hue and which causes the stars to twinkle. The earth and the moon appear as a marvellously beautiful double planet. A rim of red surrounds the earth, and around the red rim is a fringe of blue—both the

effect of transmitted and reflected sunlight on the atmosphere. Over the poles flicker the auroras. Through the clouds deep green jungles, yellow deserts, and pale-green steppes can be glimpsed.

Left to itself the ship would revolve for ever in an ellipse. The attraction of the sun and the planets keeps it on its course. And so it drifts week after week until calculations, which have been checked and re-checked, convince the captain that he must force himself out of his orbit. Mars will be at a certain place at a certain time. So the captain starts the rocket motor again. When he reaches Mars he does not plunge into its thin atmosphere. The ship becomes a satellite of Mars and revolves around it perhaps for weeks, or until the earth has swung into a favourable position for the return. Valier boldly considered the possibility of landing on one of the two satellites of Mars and using it as a base for exploration of the planet before the homeward voyage began.

The return to the earth's surface is not without its dangers. Elaborate braking devices have been devised. Backfiring rockets are to retard the ship. The danger of the rocket's melting by mere friction with the atmosphere is very real. Meteors flare up in the sky at a height of about sixty miles. Most of them are consumed before they strike the earth—burned up by rubbing against the rough air. A rocket ship is an artificial meteor. Why should it not be reduced to drops of incandescent metal? Here we have another reason for a low starting speed. The descent is especi-

ally perilous because of the high speed at which the earth's atmosphere is encountered. Entering closed gliders, the passengers coast down the air in vast spirals to the earth. Parachutes, too, are provided. Nearly all the astronauts see nothing for it but to abandon the ship and let it dash itself to pieces.

According to Prof Moulton, 'more than 20,000,000 meteors strike the earth daily'. Other astronomers place the number as high as a billion a day, including, of course, even masses as small as peas. But the energy! What if 10,000 meteorites, fine as dust, could be held in the hand, according to the estimates of Drs F. A. Lindemann and G. M. B. Dobson? In its brief flight each gives up energy enough to make 100,000 ordinary incandescent lamps glow.

The average height of 106 meteors that streaked across the sky while W. F. Denning, a well-known British authority, observed them was 73·6 miles. These 106 meteors darted into and out of sight at an average speed of 26·9 miles a second, but speeds as high as 62 miles a second have been observed. A grain of sand endowed with so much energy can kill. Luckily for us, nearly all meteors are burned up in the atmosphere by mere friction.

Obviously the scientific invader of interstellar space, hurled along by the reaction of a highly concentrated fuel, must be prepared to encounter hundreds, perhaps thousands of meteors. He cannot avoid them even if he sees them. What is his speed compared with theirs of more than 100,000 miles an hour? His rocket

craft may be pierced through and through by something no larger than a grain of sand.

The consequences of the rocket ship's advent end not with the mere exploration of the nearer regions of the solar system. Over and over again the astrophysicists have assured us that the earth must ultimately be reduced to a cold cinder swimming around the sun. The atmosphere will disappear. Oceans and lakes will dry up. What is the destiny of the human race? Must the last man die of starvation and thirst? Possibly the rocket ship is man's last hope. By the time the earth has become senile and unlivable, Venus will be ripe for intelligent beings. So it may happen, aeons hence, that Venus may be colonized by the earth as America was once colonized by Europe. And the earth will wheel around its orbit, an abandoned, planetary wreck of its former luxuriant green self.

VI. Explorers of the Atmosphere

A MILLION YEARS AGO, WHEN MAN WAS STILL HALF APE, he looked about him and wondered. Those twinkling lights in the dark sky at night—what are they? That huge ball of fire that rises high in the heavens, only to sink again at evening—what is it? Whence does it come? Whither does it go? These trees, this hard ground beneath the feet—how far do they extend?

For all our telescopes and spectroscopes, our observatories and laboratories, our mathematical accomplishments and cosmic theories, we are much like that primitive savage, distinguished from the brutes below by his ability to ask questions. With him science began. For science is concerned entirely with asking questions about man and his environment—the right kind of questions—and finding the answers.

Among the earliest of these questioners who belong to our species of humanity were the explorers, the strong-framed savages, and the Vikings who boldly pushed out towards the setting sun on unknown seas or picked their way through equally unknown forests. They are commonly regarded as adventurers thirsting for excitement. They were also scientists. Consciously or unconsciously they were trying to answer questions. Where am I? How far can I travel on foot or in my boat? What is out there where earth and sky meet?

Columbus, da Gama, Magellan, van Diemen, Captain Cook, Peary, Amundsen, Scott, Shackleton, Byrd—all are lineal descendants of the primitives who roamed and who fought with wild beasts and braved privation and disease to find out more and more about

this earth. Magellan's circumnavigation of the globe was a colossal scientific experiment. It proved experimentally the correctness of the theory that the earth is a round ball.

For centuries man has been thus crawling over land and sea like some intelligent insect. At last he has learned the more important facts about the planet on which he lives. He knows its general shape and size. He is like a stranger in a house once mysterious because it was unknown. It is possible for him to draw floor plans—what he calls charts and maps—and by their means to find his way about.

And yet this is but a beginning. There is more to the earth than land and sea, mountain and desert. Probably it never struck Columbus that the air we breathe is part of the earth, something to be explored like the more tangible ocean. He accepted it merely as a necessity of life. It is only in our own time, by which we mean the last century or so, that the wistful gaze of the explorer has turned upward to the clouds. The balloon and the airplane have given him new powers. No longer is he a two-dimensional adventurer poking into this valley or groping in that unthreaded forest, clambering up naked, snow-capped peaks or creeping over blazing, yellow sands. A three-dimensional scientist now, he must rise into the air to answer new questions about the earth. How far does the atmosphere extend? What is its relation to clouds, auroras, lightning, meteors, and for that matter to land and water, to green leaf and to man himself? A million years of

questioning has at last given him a cosmic outlook.

One fact at least the early balloonists, first explorers in three dimensions, succeeded in establishing: there is a limit to the extent of the atmosphere. Men gasp and die if they ascend high enough. Yet far above the dying altitude, as it may be called, there is still an ocean of air. For all we know, the atmosphere may reach outwardly from the earth hundreds of miles, but without the aid of oxygen a man cannot breathe much above six. Even with oxygen it is doubtful for technical reasons if he can attain more than fifteen in a balloon.

Suppose that Columbus had been in a similar predicament in 1492, that he could not venture more than a mile or two from the shore without perishing, that he had reason to believe that there was land beyond the ocean in the west. Thirsting for answers to his questions, imagine him resorting to automatic devices. He invents a little ship without a soul aboard which sails off to the west. It is packed with mechanism, almost as human as Columbus himself. The automatic instruments write down the physical facts about the voyage—the storms that are encountered and above all the unknown obstacle (land) beyond which it could not go and its distance from Spain. Spontaneously the vessel turns round and sails back. Columbus reads the records made by the instruments and infers what he can about a country to the west.

It is by a similar method that the modern Columbuses of the atmosphere, the earth's invisible rind,

must conduct some of their explorations.

Before 1896 it was supposed that with increasing altitude the air grows thinner and thinner and colder and colder. All this was true, but it was only a fraction of the truth.

Systematic exploration by Teisserenc de Bort dispelled this conception of a one-piece atmosphere. That assiduous French meteorologist, from 1896 on, sent up free, unmanned sounding balloons freighted with automatic instruments which wrote down what they felt—temperature, pressure, and other facts of interest to scientists. At first he could hardly believe the scripts that were recovered. They told a story as astonishing as any that Marco Polo brought back from the empire of Genghis Khan or Columbus from the land that lay across the ocean to the west.

More than six miles high, said the scripts, lies a strange layer of air, a layer as different from the air we live in as the Arctic is from Yucatan. There are no clouds, no storms, nothing that we designate by the word 'weather'. One day is like another. Never is the air thickened even by a mist. The sun and the stars blaze in a black sky. There reign eternal silence, serenity, and cold—cold that goes down to minus 70 degrees Fahrenheit.

De Bort and the meteorologists of his day spoke of the 'isothermal' or 'uniform temperature' layer. Later he coined the word 'stratosphere', and designated by 'troposphere' the dense stratum of air which hugs the earth's surface and which we breathe. Although tropo-

sphere and stratosphere are rather sharply separated, their boundaries vary. Between them lies the tropopause, a kind of no-man's land. The stratosphere is lowest at the Poles (about six miles) and highest in the tropics (ten miles).

A scientist on the moon armed with a sufficiently penetrating telescope would probably be able to distinguish troposphere from stratosphere. To him the air would appear as a bluish mist bulging at the earth's equator. Deep down he would note a thick, disturbed sediment. In these dregs, stirred by winds, life flourishes, oceans wash continental shores, airplanes fly. Luckily for us the sediment is a mechanical mixture of water vapour, nitrogen, oxygen, and carbon dioxide, with barely detectable quantities of helium, argon, krypton, niton, xenon, and neon—luckily, because there are enough possible chemical combinations to blow up the whole planet.

Even before Auguste Piccard made his first ascent, men had attained the stratosphere. There were Glaisher and Coxwell, who, on behalf of the British Association for the Advancement of Science, rose on September 5, 1862, swooned away, yet miraculously returned after having attained a height which was probably 11 kilometres, or 6·8 miles. And there were Berson and Süring, two Germans, who floated up to 10·5 kilometres and, despite their oxygen masks, were unconscious for at least a quarter of an hour.

In 1927 Captain Hawthorne Gray of the U.S. Army Air Corps drifted off in an open basket to a height of

eight miles, only to die on the way down as the result of exposure to the thin air. Aviators have climbed into the stratosphere time and time again, one of them being Captain Albert W. Stevens, who participated in the ascents to the stratosphere sponsored by the National Geographic Society and the U.S. Army Air Corps in 1934 and 1935. In October 1928 he soared 39,150 feet in an airplane over Dayton, Ohio.

It would be unfair to these adventurers to dismiss them as mere athletes of aeronautics. Glaisher and Coxwell, Berson and Süring, Stevens and his companions, were certainly animated by purely scientific motives. Yet it cannot be denied that all attempted to break the height record.

The astonishing fact is that although balloonists of the last century had actually entered the stratosphere seventy and more years ago, they were not aware of the strange new atmospheric world. Nothing but the cold and the tenuity of the air struck them. The information brought back by them and their immediate followers at the risk of their lives was scarcely worth the expenditure of time, effort, and money entailed. It was the meteorologists on the ground with their six-foot hydrogen balloons and instruments, mere automata, who discovered the stratosphere. In fact they have thus plumbed the atmosphere to a height of about twenty-one miles.

The concentrated attack on the stratosphere of late years was brought about by the discovery and study of the cosmic rays, strangely linked with radio-activity.

We go back to the early years of the century. Uranium, thorium, radium, polonium, and other radio-active elements were the marvels and puzzles of the day. They gave off rays of various kinds. Many famous springs turned out to be radio-active. From the earth's rocks came energy that could tear away electrons from atoms and thus ionize them—make the air conduct electricity as a wire does.

What could be more natural than to measure the amount of this ionization or electrification? Prof Theodore Wulff, a Jesuit priest, took some instruments to the top of the Eiffel Tower in Paris and saw that the effect was somewhat less there than on the ground—just what he expected. Still it seemed to Wulff that the decrease was not so marked as it should have been. Thereupon Prof Gockel, a Swiss physicist, conceived the idea of going up in a balloon and measuring the effect of radio-activity as he rose. In 1910 and 1911 he reached heights of about 13,000 feet and came down more puzzled than when he went up. The effect was indeed weaker at first, but to his astonishment it grew stronger as he rose.

Struck by Gockel's results, Dr Victor F. Hess, later crowned with the Nobel Prize for his work, did some figuring which led him to conclude that the gamma rays of radium, the most powerful agency supposedly involved, ought to be absorbed entirely a few hundred yards above sea-level. Either Gockel was wrong or his observations were worth repeating. So Hess sent up unmanned balloons with recording instruments.

Heights of 16,000 feet were reached. There was no doubt about Gockel's findings. The rays were stronger at great heights than near the earth.

Hess went up in balloons himself and later collaborated with Prof Kolhörster in making measurements at heights of nearly six miles. Always the same result. The rays undoubtedly grew stronger with increasing altitude. There was only one conclusion to be drawn. These rays had nothing to do with radio-activity. They came either from the earth's atmosphere or from outer space. Moreover, they were of tremendous energy. Even the gamma rays were not so penetrating. To Hess must go the credit of having recognized the cosmic character of the rays.

In 1925 Prof Millikan decided to enter this strange new field of exploration. He sent up unmanned balloons from Kelly Field, Texas, struggled up mountains in Bolivia, climbed Pike's Peak with 300 pounds of lead and a tank of water, scaled Mount Whitney in order to lower instruments into snow-fed Lake Muir, journeyed to the Arctic regions to make more observations there, and even rose as high as he could in airplanes with ingenious devices of his own construction. Not only did he confirm what his predecessors had discovered but he published much more accurate records.

Then came the great question: what are these rays? To Millikan the rays are simply waves of light, but of a shortness, penetration and energy previously unknown. They can pierce eighteen feet of lead. Even

at the bottom of Lake Constance—775 feet—they can be detected. They are not observed directly as we observe daylight. By their effects alone are they known. They tear away electrons from air atoms. The electrons in turn run amuck for a few moments and wreck other atoms—even their very cores. All that the physicist sees is the fragments of wreckage.

Prof Arthur H. Compton was attracted by the mystery. He organized and directed a world-wide survey which eventually led him to the conclusion—already reached by Clay, Kolhörster, and others in Europe—that the rays are for the most part bits of matter or particles. There can be no doubt that they are stronger near the Poles than at the Equator, which is exactly what is to be expected if they are electrified particles. The earth is a huge magnet. Theoretically it ought to draw such particles to its poles.

We see, then, that mountain-climbing and ballooning have always been a part of cosmic-ray research and that the stratosphere is as important to the atomic physicist as it is to the meteorologist. To the upper air a scientist must of necessity go if he would run down the cosmic rays to their origin. It must be confessed that thus far the quest has not been successful. Prof Regener, like many of his predecessors, has sent up unmanned sounding balloons with instruments, to discover if the rays continue to increase in strength indefinitely. On one occasion his balloons attained a height of 22 kilometres or 13·66 miles.

More ascents must be made to settle the question of the origin of the cosmic rays. Besides, the stratosphere turns out to be worth investigating on its own account. Here is a region inundated by rays from which the troposphere shields us—ordinary sunlight, but of a fierceness unknown to us; ultra-violet rays, infra-red rays, cosmic rays, an endless stream of electrons from the sun, and possibly other particles of which we are not even aware. Farther out, at thirty-five miles, beyond the range even of sounding balloons, there seems to be an active ozone layer where the air is as warm as at the earth's surface and where a man's shout could be heard. Still farther out, at sixty or sixty-five miles, there is an invisible electron mirror that reflects wireless waves around the earth. And beyond that still another.

We begin to see why physicists have suddenly become expert, record-breaking balloonists. Height, more height is their cry. Six miles is not enough. Eight, ten, fifteen scarcely satisfy. To float up wearing an oxygen mask and the furs of an Arctic explorer is an insuperable handicap. The hands must be free. A man must be able to move about if he is to accomplish his scientific mission. He must be kept warm without clothing himself in an electrically heated suit thicker than a bed-quilt.

State the problem thus and it becomes apparent why Piccard decided to abandon the old, open balloon-basket. He conceived the now familiar globular gondola or car—a hermetically sealed hollow ball of

light metal in which two men can live in comfort for a few hours, breathing oxygen as it escapes at a measured rate from a steel flask, reading instruments, looking out of port-holes now and then, noting interesting phenomena in a log-book.

It must be said that when the world first heard of this proposal it classified Piccard as a mild crank of the inventor type. To be sure, he was a professor, but he was not an outstanding figure in the world of physicists. The pictures of him that were published boded no good. That long, studious face, with the spectacles, that intellectual brow, that bald head with the fringe of unfashionably tousled hair might belong to a tutor of the Second Empire, but not to an adventurer who could successfully rise to heights never before attained by a human being.

But Piccard proved that a square jaw and a rugged, athletic frame are the least important requisites of one who dares the unknown in the atmosphere. An obscure Belgian professor haunted by the mystery of the cosmic rays, he made the one noteworthy advance in free ballooning since hydrogen was introduced for the inflation of gas-bags. Every ascent into the stratosphere by balloon since 1931 has followed the principles that he laid down. He is the first of a new race of explorers. What began with him solely as an effort to obtain more information about the cosmic rays has awakened such interest in the stratosphere that a new era of discovery has been inaugurated, an era comparable with that which began with Columbus in 1492.

Soviet physicists were the first to take this larger view and to rise into the stratosphere for something more than the accumulation of facts about the cosmic rays. They took up with them not only the usual electrical devices that record the intensity of the cosmic rays and the direction from which they come, but also a battery of instruments which would enable science to enlarge its knowledge of the upper atmosphere. A larger balloon than theirs can lift more instruments, bring back more facts, and possibly ascend even higher into those upper reaches of the air which are already known to harbour wonders as startling as any discovered by the early navigators who pushed out into unknown seas.

So under the auspices of the National Geographic Society and the U.S. Army Air Corps two balloons, *Explorer I* and *Explorer II*, were built in 1934 and 1935. The first of these came to grief on the descent from 60,000 feet, but at about 18,000 feet Major Kepner, Captain Stevens and Captain Anderson leaped for their lives with parachutes.

The *Explorer II* was the largest balloon ever constructed. Its diameter was 192 feet, its capacity 3,700,000 cubic feet — considerably more than five times that in which Settle and Fordney rose and about four times more than that in which the Russians reached an altitude of nearly thirteen miles. So huge was the *Explorer II* that an eleven-story building could find room within the inflated gas-bag. A ton of instruments could be carried. The gondola was, in

effect, a laboratory. In this huge bubble Captain (now Major) Stevens and Captain Anderson rose to a height of 72,395 feet above sea-level, a record altitude for a manned balloon. The date was November 11, 1935.

It is only with a whole battery of measuring devices that the mystery of the stratosphere can be clarified. The unmanned sounding balloon can do no more than it has done in the hands of ground meteorologists. Beyond the facts already cited—height, intense coldness, calm, slightly rising temperature with altitude—scarcely anything is known about the stratosphere. For every fact there are ten hypotheses.

Take the matter of the composition of the air. Theoretical calculations by the most eminent authorities demanded an oxygen content of not more than 15 to 18 per cent. at twelve miles. But samples brought down from that height varied not at all from samples taken at sea-level. The amount of oxygen, in other words, was 21 per cent.—just what it is below. Now the same eminent authorities are inclined to believe that even at thirty miles the chemical composition of the atmosphere is what we know it to be. Above that level the ozone is supposed to increase. At 100 miles there ought to be noticeably more oxygen. But the principal gas would always be nitrogen at any height. Hydrogen and helium probably escape into outer space because of their lightness.

Then there is the matter of wind. Ever since the stratosphere was discovered by de Bort it has been regarded as a region of dead calm. But gases so

thoroughly mixed at twelve miles that their chemical composition is the same as on the earth below lend colour to the view that there must be at least a light breeze. Besides, the stratosphere is warmed by day and cooled by night. Such a daily variation must give rise to some wind—on the principle of the draught created by heated air rising in a chimney.

Is there, perhaps, a zephyr at the bottom of the stratosphere and less and less motion of the air as the top is approached? How true is it that the gases tend to arrange themselves according to their weights above the level of possible, gentle winds? The stratospheric navigators must answer, if they can, though the heights that can be attained in free balloons are limited.

What is the colour of the sky? It darkens, as Piccard and the Russians saw. But the records we have are good only for about thirteen miles. There can be no doubt that as a balloon floats up the aspect of the heavens changes. At 25,000 feet the welkin is a pallid grey, at 35,000 dark blue, at 42,000 violet, at 60,000 black-violet-grey, at 68,000 a purplish, brownish, or blackish grey. Such at least is the story told by the skylight recorders that were found intact in the Russian balloon after its fatal crash.

Strange phenomena are observed from the earth by the curious eyes of physicists. At forty-five miles they detect signs of a twilight, a scattering of light. But such a dispersion cannot take place in a vacuum. So the conclusion is drawn that the atmosphere extends to

forty-five miles. But what is the nature of the air?

And then what are those wondrous clouds that shimmer through the night in the northern sky? The stratosphere is certainly cloudless. Yet at fifty miles these mysterious reflections are plain enough. Meteorologists go even so far as to call them 'noctilucent clouds'. But clouds of what? Dust, perhaps? If so, how does dust manage to gather in definite layers at such an altitude? Whence did it come? From earthly volcanoes? The physicist longs for a sample. But no balloon is likely to bring it down—not even an unmanned balloon.

Far above the faëry noctilucent clouds meteors flash and auroras shimmer. The height must be at least 400 miles. Both phenomena imply an atmosphere. For meteors burn up by mere friction with the air, and auroras glow just like thin gases in a glass tube shot through with an electric discharge. So even at 400 miles there must be air. But what kind of air? And what makes the air glow? The sun no doubt furnishes the electricity in the form of electrons. But what is the mechanism?

Profs McLennan and Shrum of the University of Toronto have hurled electrons through thin oxygen and obtained a spectrum like that of the aurora, particularly a brilliant green line which has been observed for years, to the great bewilderment of physicists. Does it follow from this experiment in a laboratory that high up where the aurora glows there is oxygen?

And then there is Dr Joseph Kaplan of the Univer-

sity of California at Los Angeles, who has succeeded in reproducing the complex spectrum of the fainter lines and bands in the light of the night sky. Has he hit on the mechanism that produces the effects we see? He uses a discharge-tube—the neon sign on Main Street is such a tube—to bombard traces of nitrogen and oxygen with electrons. The energy of the electrons is absorbed by the nitrogen molecules and oxygen atoms so long as the discharge is maintained. When the barrage of electrons is stopped the molecules and atoms radiate the absorbed energy in the form of light, which is about the same as the light of the night sky. It looks as if in the rarefied higher layers of the atmosphere a steady stream of electrons coming from the sun by day excites the nitrogen molecules and the oxygen atoms, through an intermediate mechanism, so that they glow faintly. Perhaps this is the best that can be done by way of an explanation. Even an ascent into the stratosphere to twenty miles is likely to help the physicist.

VII. *The Mystery of the Atom*

WE TALK ABOUT ATOMS AS IF THEY WERE PRODUCTS OF modern scientific thinking. But the ancients postulated them centuries ago. In fact, the atom of Democritus, the Greek, goes back to 400 B.C., and his was by no means the first. Perhaps he seems especially important because he gave us the word 'atom'. All matter is composed of atoms, he reasoned. If iron, gold, and water differ, it is because their atoms are different. The Nobel prize-winners in physics cannot tell us very much more. After 2500 years of thinking about matter and experimenting with it, we have advanced only a little beyond Democritus.

The obvious way of discovering how matter is constructed is to break it up or pick it into the smallest possible pieces and to study these. But, what lies beyond visibility? Scientists must always speculate and theorize.

Atom-disintegration hardly describes what the physicists are doing to matter. To be sure, their high-voltage machines and their electric guns and slingshots strike terrific blows, break off bits, and even penetrate to the very core of the atom. But disintegration implies destruction beyond repair.

Usually the laboratory process of disintegrating is accompanied by a process of creation. In other words, the bullet that destroys, splits the core of an atom and ejects fragments, is captured and used as a building block for a new atom. So, in spite of the bombardment, an atom of some kind always remains. Which means that the physicist has not yet found a way of

entirely breaking up matter—and probably never will. Fundamentally we may never know much more than Democritus knew about matter. But it is something to discover how matter is transformed. The cosmos becomes more dynamic—becomes an evolving structure.

Even before there was atom-disintegration a few physicists had wondered if the chemist's atom was actually the type of fundamental brick of which the cosmos was built. There are nearly a hundred different atoms. Can the fundamentals of nature be so complicated? Is it not more likely that they are very simple?

Some shrewd guesses were made. One of the best was that of William Prout, an astute physician and physicist. In 1815 he decided that hydrogen was the primordial stuff of the universe. An extraordinary guess—this; a fine approximation of our own views.

Success in atom-destruction and an approach to the rock-bottom of the universe came largely as the result of accident. There was Sir William Crookes, a skilful, imaginative chemist who experimented at length with a glass tube from which he pumped as much air as he could, and in the ends of which he sealed electrodes. When he connected the electrodes with a source of current the gap between them was bridged by a beautiful glow. Crookes held an electromagnet near the tube. He saw the glow bend towards the magnet, just as if it were composed of iron particles. 'Cathode radiation' the glow was called because it originated at the par-

ticular electrode called the cathode.

Can this be light? Crookes asked. Whoever heard of sunlight, candlelight, gaslight, any kind of light, influenced by a magnet? He began to address scientific groups on 'a fourth state of matter'.

This mystery was cleared up by J. J. Thomson, destined to become one of the greatest physicists of his day. The glow was electric—so much was sure. A few daring minds had suggested that perhaps electricity was composed of atoms just like matter. Thomson made some measurements which convinced him that electricity has mass—a property supposed to be confined to matter. Then came a day when he could announce that the cathode rays were particles of negative electricity smaller than atoms. In fact, the hydrogen atom, lightest of all, was more than 1800 times heavier than one of these particles. With this discovery the old-fashioned atom was doomed.

The exhausted tube with which Thomson experimented was the first atom-bombarding gun. Its glow was the visible evidence that atoms were being smashed. Electrons streamed from one end of the tube to the other. Sometimes one would hit an atom of gas which the pump had not removed. A negative electron was then ripped off. Whereupon the atom would glow in a sort of electrical anguish. Thomson tried gas after gas. Always the flying electrons knocked off electrons from gas atoms. And the electrons were always the same.

So Thomson came to this view: an electric dis-

charge in a tube is composed of electrons and partly destroyed atoms (ions). Atoms are composed of electrons. Perhaps electricity (energy) and matter are merely different manifestations of the same thing. The electron theory of matter was born, and with it a revolution in physics.

But how was the atom constructed? Thomson knew that negative electrons must be held in the neutral atom by some force. So he imagined a sphere of positive electrons in which his negative electrons were buried as in a jelly. Two forces opposing each other would give us neutral atoms—gold, tin, or gas atoms.

Was the hypothesis correct? Young Ernest Rutherford, one of Thomson's students, decided to find out. He needed some instrument which could deliver more demolishing blows than streaming electrons in a Crookes tube. Nothing that science had invented would do. He turned to radium. It shot out rays of three different kinds. One kind consisted of alpha particles, cores of helium atoms. These the radium hurled from itself with a speed of 12,000 miles a second. They were many times heavier than negative electrons, and they had a terrific hitting power because of their speed. Let these heavy, swift alpha particles bombard a bit of matter—a piece of tissue-like gold-leaf, for example—and what would happen?

Even with these faster, heavier bullets it was hard to blast atoms apart. Rutherford found that when a bullet, an alpha particle, did strike home it was turned aside just as a baseball is deflected from a stone wall.

There must be something hard inside the atom, reasoned Rutherford—something like the stone of a cherry. He fired alpha particles at atoms of nitrogen gas. Out flew an entirely new particle, a proton as he called it, a piece of hydrogen, a positively charged particle. Hydrogen coming out of nitrogen? But this was the transmutation of matter about which alchemists had dreamed!

Rutherford fired alpha particles at boron, sodium, aluminium, phosphorus, fluorine. Always cores of hydrogen or protons flew out of the struck atoms. There was only one conclusion—protons (hydrogen) must be the basis of all matter. Old William Prout was right.

Neither Thomson nor Rutherford had demolished the atom. But they had chipped it. Thomson's chips were outer electrons; Rutherford's, inner protons. Both kinds could be deflected by magnets.

Rutherford's way of bombarding the nucleus with alpha particles has never been abandoned. Its possibilities are not yet exhausted. Profs Walther Bothe and Wilhelm H. Becker of the University of Giessen tried it on beryllium. Powerful rays came out. Rays of what? Gamma rays, thought Bothe and Becker—rays like X-rays, but much more penetrating. Radium sends them out too.

Pierre Joliot and his wife Irène Curie repeated the experiment. They saw the rays easily passing through lead but not so easily through paraffin-wax, cellophane, or hydrogen.

Rutherford's associate in Cambridge, James Chadwick, was interested. He, too, verified the existence of the new emanation. Probably because of his old association with Rutherford he saw clearly what was happening to the atom. For Rutherford in England and William Harkins of Chicago had predicted years before that there must be within the atom not only alpha particles, protons, and electrons, but something which Harkins called a neutron, a particle which is neither positive nor negative. Chadwick announced the neutron—the sensation of 1932. The whole conception of the atom had to be revised.

The neutron has turned out to be a boon, simply because it is neutral. Alpha particles, protons, electrons—these have definite electric charges. They may chip a nucleus, but in the end they are deflected. This neutron penetrates.

It has become the fashion now to fire alpha particles at beryllium and let the neutrons that fly out bombard other atoms. With their aid it has been possible to excite such quiet elements as nitrogen and sodium into radio-activity. Hopes are aroused that artificial radio-activity may become so cheap that expensive radium may be dispensed with in the treatment of cancer.

In 1933 Dr Carl Anderson, of Millikan's laboratory, looked at some photographs of gas atoms wrecked by cosmic rays. Streaks presented themselves to his eye, like meteor trails. But one trail was bent differently from the rest. Why? An electromagnet had pulled

negative electrons aside. This was Crookes's old experiment. That one trail was bent in the opposite direction.

Anderson was quick to grasp the significance. He beheld the luminous wake of an entirely new particle —the positron. It turned out later that cosmic radiation is in part composed of positrons. That they are constituents of matter follows from the fact that when some elements are bombarded by gamma rays (very powerful light-bullets shot out by radium) out fly a positron and an electron from the same place. At any rate, one mystery was cleared up by Anderson's discovery. The proton was the positive or electrical opposite of the negative electron. Physicists had predicted something that must be not only the electrical opposite but the mass-opposite. Now they had it.

And still the physicists are not satisfied. They foretold the neutron and the positron. Now they foretell the neutrino and another particle which is the negative opposite of the positive proton.

With each new discovery about the atom it has been necessary to revise the conception of its structure. One by one the models have gone. For Thomson's positive jelly in which negative electrons were imbedded, Rutherford substituted an atom with a dense nucleus around which electrons revolved like planets. When it turned out that a mechanical atom should have collapsed ages ago — and with it the universe — physicists accepted the Bohr atom. In this the electrons jumped from orbit to orbit as they gained or lost

energy and emitted light and heat as they did so. When this conception failed to explain all that happens to matter the mathematicians took possession of the atom. What we have now is a lawless abstraction of which it is impossible to form any mental picture—a figment of the scientific imagination, a wraith.

Let us not forget that atoms, protons, electrons, positrons, neutrons, alpha particles are but inferences. All that the physicist sees are lines and bands in a spectrum, deflections of glowing streams by electromagnets, radio-active effects in matter, splashes on luminous screens, streaks of light on photographs, bendings and forkings of meteor-like trails, as particles plough their way through a fog in a little chamber.

The scientist simply has to theorize. So he creates the atom, the electron, the proton, the neutron, and all the other particles with which we have become acquainted. Does this mean that atoms and even smaller particles have no existence? No one can maintain that. But we shall never see any of them. In all nature there is no such thing as *the* atom or *the* electron, as theory demands. All are abstractions. Nor is there such a thing in all nature as the mathematician's point (which has no dimensions but only position) or a straight line (which has no width). A cube exists only in the mathematician's mind. Yet there are obviously cubical bodies, such as houses and boxes. An abstract atom is born of the physicist's intellectual necessity. Yet a mass of iron is undoubtedly composed

of atoms of iron. A free electron has no existence. But a stream of electrons is an electric current or a stroke of lightning.

The atom as it is seen by the great mathematical physicists of our time — Compton, Sommerfeld, Schrödinger, de Broglie, Bohr, Planck, Heisenberg— is a kind of symphony. Just as a composer puts down certain notes on ruled paper and gives them certain intensities, qualities, and relationships, so the physicist composes an atom of protons, electrons, and neutrons. Both in music and in mathematics we deal with symbols to which definite values and meanings are given.

Suppose that nobody on earth had ever heard a piece of music. Then suppose that Beethoven's Fifth Symphony were played over and over again by invisible musicians. It would be the physicist's problem to devise an apparatus which would sift out one note from another and analyse it, infer what kind of invisible instruments produce the sounds, deduce the rules followed in determining what notes should be played and how long and how loudly. It is not likely that he would succeed in imagining violins and clarinets or even musicians blowing into horns. He would postulate merely vibrating bodies. These would meet his requirements. Even with this simplification the odds against his completely probing the mystery of Beethoven's Fifth Symphony played by unknown means would be heavy.

The analogy between a symphony and an atom is more accurate than may be supposed. We cannot make

a model of a symphony as we can of a house. Neither can we make a model of the atom as it is now conceived, because there is nothing tangible about it. We cannot talk about Beethoven's Fifth Symphony and hope to make anyone who has never heard it understand how it sounds. Nor can we talk about the atom in terms of protons, electrons, and neutrons in the hope of making anybody who is not a good mathematician understand how it emits particles if it is a radium atom or why it sends out light when it is electrically excited.

Music is composed according to rules. The composers of the atomic symphony must also follow rules. They must give us an atom that harmonizes with the known facts about matter. They must explain why it is that the neon in the tubes of Main Street's lights glows red, why heat comes out of red-hot iron, why roses are red, why hydrogen is a light gas and lead is a heavy solid. It takes the highest type of intellect to deduce the fundamentals—deduce not only how the atom may be constructed but why it behaves as it does, why it radiates energy just as an invisible orchestra radiates a symphony.

It turns out that we have to give up the idea of a machine atom, meaning something that does predictable things Spin a dynamo and everybody knows that electricity, a stream of electrons, will pour out. But nothing can be predicted about individual atoms or about their individual electrons or neutrons. The methods of the statistician have to be applied—

methods somewhat like those invented by the life-insurance actuaries to determine the mean expectancy of life at birth. Where the individual electron may be within the atom, what it may be doing, no one knows. But what the average electron is doing—that can be determined to some degree. Unfortunately, the average electron has no more a tangible existence than the 'average man' of the statistician. Yet it is a necessary conception.

Because the old 'natural laws' have broken down within the atom, because there is nothing like a machine, our whole conception of the universe has changed. The more revolutionary physicists rejoice. To them cause and effect—the idea of the machine—is a relic of a savage way of thinking. We no longer believe that Boreas puffs out his cheeks to make the wind blow from the north, that angels push the planets around, as Kepler believed. Similarly, according to the revolutionists, it is time that we gave up the childish notion that every effect has its cause.

Out of atom-bombarding, out of the intellectual effort to explain what the atom is, comes a new, profound, and stirring conception of the universe and our place in it. Everything was not fore-ordained with the great act of creation, as the world believed only a generation ago. We are free agents again. The mathematical physicist who once had nothing but contempt for the philosopher because he was not an experimenter has of necessity become a philosopher himself. If atoms, electrons, and all the other particles, con-

sidered as theoretical individuals, are creatures of the mind, if it is impossible to make measurements without injecting the mind into them, the old Gradgrind conception of the universe must go.

Something lies outside of ourselves—of that the physicist is convinced. But what it is, his symphonies about the atom do not tell. Yet out of this questioning comes a revolution in thought as destructive as any that we owe to Copernicus, Galileo, and Newton. What the ultimate effect will be on art, religion, science itself, no one can foresee. But it is at least certain that when atom-shattering began there also began a shattering of much scientific and philosophic self-satisfaction.

VIII. *After Coal—What?*

PROBABLY AS EARLY AS THE YEAR 2500, CERTAINLY NOT later than 3000, the last lump of coal in the form of coke will be flung into a furnace. A century later museums will pay as much for a slab of British cannel or American steam coal as for a dinosaur's egg. And the slab will bear a label reading:

Seminole Coal

Between 1800 and 2500 (the so-called 'Coal Age') energy was derived mainly from fossil wood or coal. This slab was mined in West Virginia a few hundred miles from what was once a thriving but gloomy industrial region of which Pittsburg, Cleveland and Philadelphia were the principal centres. Coal was first burned for the generation of energy after Newcomen invented the steam pump in the eighteenth century. A century later the steam-engine (James Watt) was generally introduced in Europe and America for all industrial purposes. By 1900 coal became of such economic and therefore political importance that it figured in the treaty of peace signed in 1919 at the end of the World War.

China (1982) and the Antarctic (2025) were dismembered for their coal deposits by the United States, Great Britain, France, and Germany, acting through the International Coal Consortium. By 2500 about two thousand million tons had been mined throughout the world, after which it became technically impossible to work the deeper seams. About half of this coal was not distilled but ignorantly burned and there-

fore wasted. Prices rose steadily from 25 cents a ton at the mine in 1850 to over $300 a ton in 2000, so that, even with the utmost thrift in the development of by-products (see next case) and the compulsory adoption of the mercury turbine, industries gradually abandoned coal for other energy sources.

The truth is that for about fifty years governments, engineers and economists have been concerned about our coal reserves. In 1910 the late Sir William Ramsay, one of the greatest of English chemists, rose before the British Association for the Advancement of Science and pronounced England's doom. The scene was like that in a novel by Wells. A great scientist was warning his country, still foremost in industry and commerce. Her supremacy rested on coal, and her coal could not possibly last more than one hundred and seventy-five years. There are those who were present and who remember the hush that fell on the audience. Not for years had any scientist so deeply stirred his peers. England fated to go the way of Egypt, Greece, and Rome! It seemed incredible. And yet the figures of coal production and consumption could not be contested. The rest of the world was in a similar plight, though not one so immediately alarming. On the whole, there was enough coal to keep the world going for perhaps a thousand years. What then?

Just as in a Wellsian novel, Parliament was sufficiently aroused to take action. The British Science Guild was asked to survey known and unknown ways

of driving machinery. The rise and fall of the tides, the energy of wind and waterfall, the internal heat of the earth, the chemical energy of wood and peat, the store of energy in the atom, even the spinning of the earth on its axis and its motion annually through space, were critically examined. So desperate was the manifest need of coal that no suggestion was wild enough to be summarily rejected. Other British commissions have studied specific energy sources since that historic meeting of the British Association.

Coal is so convenient and we are so thoroughly trained in its utilization that we shall not see a sudden change but a transition to some other source of energy. Deeper and deeper the engineer will dive, cut, and blast. How far can he go? No one knows. Mines are now worked at depths that seemed hopeless fifty years ago, because engineers have devised better ventilating systems, machines for cutting coal, efficient hoists, and electric locomotives. Depths will be reached that seem fantastic now. When they are, the engineer will be brought face to face not with coal but with heat—the internal heat of the earth, heat so intense that it can take the place of fuel. The deeper a shaft is sunk, the higher is the temperature encountered. In the Village Deep Mine in Johannesburg circulating air becomes so hot at 7000 feet that it could generate 3000 horsepower were it suitably applied.

Suppose, then, we bore for heat. Energy far beyond the requirements of the United States could be obtained from a single hole. Sir Charles Parsons, inventor

of the steam turbine and one of the great engineers of our time, once laid such a plan before the British Association for the advancement of Science. Sink a shaft to a depth of twelve miles, he urged. The cost? From £5,000,000 to £20,000,000. And the time? From fifty to eighty-five years. Engineers objected. The rock would cave in and crush the shaft. Whereupon Prof Frank D. Dams of Montreal made a few experiments which proved that in limestone and granite depths of fifteen and thirty miles, respectively, are practicable. To Parsons the expense incurred seemed trivial compared with the benefits to be derived —new light on the constitution of the earth, beds of radio-active minerals, gold and other precious metals, and, above all, power, unlimited power from hot rocks.

The technical difficulties that must be faced if Parsons' proposal is actually carried out are formidable. As the miners descend, the temperature rises. How can they endure the heat? Clothing them in suits inflated with chilled air was the solution of John Hodgson, an English engineer, who likewise believed in tapping the earth for power. Means must be devised for driving the shaft in the face of boiling-hot water gushing from subterranean springs and for ventilating working spaces on a scale still unattempted. New shaft-linings must be designed, linings capable of resisting gigantic pressures.

If the earth is to be mined for its internal heat, the steam-engine must still be accepted as an indispensable

prime mover. Granting this and granting that a depth of miles must be reached, power-houses may be built underground—power-houses in which the same temperature will prevail the year round and in which an artificial climate will always be maintained. The men in the power-house will travel vertically to and from their homes a distance greater than that now covered daily by the average suburbanite who works in New York and sleeps in New Jersey.

Long before heat-mining companies are organized, industry will turn to the tides in an effort to save itself. What can be easier and more obvious than to let the moon raise water over the face of the earth and to impound that water in a reservoir, so that it may run down through a pipe and drive a water-wheel by which electricity is generated? Easy and obvious—but expensive compared with the cost of a steam-plant in this first half of the twentieth century.

At the Severn Estuary, where the rise is twenty-eight feet and an area of forty square miles is involved, a power-plant would cost £30,000,000 at prevailing prices for material and labour. About £20,000,000 would be required to develop the sixty-foot tides of the Bay of Fundy at Passamaquoddy. Only when England is brought face to face with a coal crisis will the Severn become a source of power. Passamaquoddy has possibilities even now. There 500,000 horse-power can be developed if a market can be found. England will certainly develop her tidal power by the year 2000. A special commission appointed as the result of

Ramsay's prophecy has located all the suitable sites for tidal-power plants in the British Isles. One whole study was devoted to the Severn alone.

There are seventy-two places in the British Isles where the tidal rise and fall of water exceeds ten feet and where a continuous output of at least 1000 horse-power can be realized. Four million horse-power might even now be generated in Great Britain and Ireland by letting the moon elevate water. But only 40,000,000 tons of coal would be saved annually. Great Britain's annual production is about 230,000,000 tons. Clearly the moon and tides alone cannot save Great Britain from industrial extinction. Yet the day will assuredly come when a Londoner will point to a street-light and say: 'D'ye see that lamp yonder? A kind of bright moonlight. Lit by power from the Severn, and the power comes from the moon.'

Note that in all these schemes for utilizing the tides we rely on what is in effect an artificial waterfall. Why not use the energy of natural falls and thus dispense with all this cumbrous mechanism? In a hundred years every waterfall in every civilized country will undoubtedly be developed. But the salvation of our industrial civilization lies not in tumbling cascades. If every available stream in the United States were fully utilized for power we should still be ruled by steam and coal. The truth is that there is not enough energy in natural falls to meet even the present demands of the United States.

For the world as a whole the situation is only

temporarily more favourable. Assuming that all the waterfalls in the world were now developed, and that even those in unpopulated regions were somehow electrically driving the wheels of industry in far-distant countries, civilized humanity would just about be able to meet its present energy demands. No doubt Essens and Pittsburgs will spring up near the Victoria Falls of the Zambezi, Africa, and on other continents where cataracts roar almost unheard in jungles now given over to wild animals and dense vegetation.

Granting all this, the world's need of industrial energy grows year by year. In another century the combined resources of the world's water-power will prove inadequate. The United States typifies the industrial nation of the future. Even now the capacity of our constructed hydro-electric plants is nearly equal to that of all European water-power plants combined. A few favoured countries like Switzerland, Norway, Italy and Japan may possibly survive because of their abundant water-power. The world as a whole must look to other substitutes for coal.

The problem is further simplified, so far as forecasting is concerned, by the extraordinary efficiency to which the water turbine has been brought. One hundred per cent. efficiency is clearly the maximum attainable in any machine. The water turbine is already about 90 per cent. efficient. Hence the slight improvement still to be made cannot mean that, through some streak of genius, we may make a

waterfall develop much more energy than is now thought possible.

There is more hope in sea water—not for England but for the tropics. And that hope depends on the difference in temperature that prevails between the surface and the bottom. The higher the waterfall, the more power at the shaft of the water-wheel; the bigger the temperature-drop, the bigger the power-potentialities.

In this principle Georges Claude, a distinguished French chemist and engineer, sees salvation. 'There is an inexhaustible store of power in tropical waters, which, if utilized, will change the whole character of equatorial communities now lying industrially dormant,' he told the French Academy of Sciences. 'The construction of the necessary plant is no more difficult than laying a transatlantic cable.'

Claude happens to have made a fortune out of liquid air, synthetic nitrogen, acetone and neon lamps, and is, therefore, able to indulge in more than prophecy. In Cuba he built an experimental power-plant which had neither roaring furnaces nor tall chimneys. To him it was the harbinger of a new coalless power era; for it was to generate energy merely by letting heat run downhill as if it were so much water. Claude selected Matanzas, Cuba, for his experiment because there he found two temperatures sufficiently far apart. The surface temperature of the sea in the torrid zone varied from 79 to 86 degrees Fahrenheit. At a depth of 2000 to 3000 feet a ther-

mometer registered from 39 to 41 degrees Fahrenheit. If the temperature of the surface could be transferred to that of the chilly depths, a steam engine could be driven in the process.

Water boils at 212 degrees Fahrenheit. How, then, can steam be generated at 86 degrees, the temperature of surface water in the tropics? Boiling-points are determined by atmospheric pressure. Remove the pressure partially and the boiling-point is lowered. On the top of a mountain water boils more easily than at sea-level because the atmosphere does not press down upon it so hard. Pump the air out of a vessel and it is easy enough to make water boil at ordinary room temperatures. A vacuum pump was therefore an indispensable part of Claude's equipment. The pump created a partial vacuum which caused water drawn from the surface of the Gulf of Mexico to boil. The steam generated drove a turbine and then passed to a condenser which was cooled—by what? Sea water lifted from a depth of 2000 feet—sea water which was only a few degrees above the freezing-point all the year round. Thus the steam exhausted by the turbine was condensed and a vacuum was created which extended back through the system. The steam naturally rushed towards the vacuum in the condenser, tried to fill it, and in the process pushed against the blades of a turbine. So the shaft of a dynamo was turned. The starting vacuum pump was cut off after the water in the 'boiler' began to give off steam.

This was no paper invention. Claude had actually built in Belgium a small experimental plant which ran with a temperature-drop far less than that at his disposal in Cuba. His Matanzas plant, though commercially unsuccessful, was as significant in the evolution of society as the steam-engine of James Watt.

Tidal power shrinks to insignificance compared with power derived from warm water in the tropics. Under the action of the tides a cubic yard of water may rise and fall a distance of perhaps ten feet, on the average. But a cubic yard of water converted into steam does at least as much work as if it fell 100 yards. No wonder Claude was impelled to say to the Academy of Sciences: 'Such a process, capable of taking from the sea the energy of ten Niagaras, will convert wildernesses into populous communities. The ocean will be harnessed in a manner never dreamed of before.'

Similar prophecies are heard from those who believe in wind-power. To be industrially useful the wind's energy must be stored. Breezes are fitful but the demands of industry steady. Hence it has been proposed time and time again that the wind be made to drive electric generators and that electricity be bottled in storage batteries. The installations are expensive and the current obtained far dearer than that furnished by any well-managed central station.

A 100,000-horse-power windmill plant is almost inconceivable in the present state of engineering. So

far as we can see now, every house and factory would be compelled to install its own windmill-electric plant if all sources of energy but the wind were suddenly cut off. Yet the imaginative J. B. S. Haldane regards wind hopefully. He realizes the deficiencies of our present storage batteries. 'If a windmill in one's back-garden could produce a hundredweight of coal daily (and it can produce its equivalent in energy), our coal-mines would shut down tomorrow. Even tomorrow a cheap, foolproof, and durable storage battery may be invented which will enable us to transform the intermittent energy of the wind into continuous electric power.'

And so, Haldane bids us imagine England 400 years hence—an England covered with metallic windmills working electric motors 'which in their turn supply current at a very high voltage to great electric mains.' Let storms rage. Great power-stations will store their surplus energy, which will in turn electrolytically decompose water into oxygen and hydrogen. 'In times of calm the gases will be recombined in explosion motors working dynamos which produce electric energy once more. . Liquid hydrogen is weight for weight the most efficient known method of storing energy. . Huge reservoirs of liquefied gases will enable wind energy to be stored, so that it can be expended for industry, transportation, heating, and lighting.'

The man who speaks is a biologist and not an engineer, yet the principle advocated is not without

engineering and chemical validity. To admit that a mechanism is theoretically possible is the first step towards its realization.

Wind-power could more than drive the world's machinery if some such storage system as that imagined by Haldane could be devised. We can do little more than guess at the energy contained in the wind, but according to the best calculations it cannot be less than five thousand times the world's annual coal production. And that is why it must receive consideration in any study of the coalless future.

Wind, coal, every form of free or latent energy, is derived in the last analysis from the sun. Why not go to the sun directly? The earth is manifestly bathed in its heat and light—both forms of energy. Engineers have calculated the amount of heat that falls from the sun on the earth. Enough is received to melt a terrestrial layer of ice 424 feet thick every year. During an eight-hour day in the tropics the sun lavishes on a single square mile energy equivalent to that released by the combustion of 7400 tons of coal. About eighteen hundred times more energy inundates Sahara than is contained in the coal mined in the course of a year. Burn 6,000,000,000 tons of coal and you unlock the amount of energy received by that desert in but a single day.

What we need is a trap to catch the sun. The first man to invent one was John Ericsson, who built the *Monitor*. He devised a huge concave mirror which reflected and concentrated the sun's rays on a black-

ened boiler at the focus and which was mechanically turned so that it followed the sun. Thin sheets of metal could be fused by solar heat.

Ericsson generated steam in his boiler and succeeded in driving pumps and other machines with the highest efficiency thus far attained by solar heat alone. Others who followed him filled their boilers with liquids that are vaporized at low temperatures —liquids such as ammonia, sulphur dioxide, and some organic compounds. Frank Shuman modified Ericsson's plan by causing water to flow in a thin layer in a long glass-covered trough on which concave mirrors concentrated the sun's rays. Thus he managed to drive a pump and to irrigate land at Mead, Egypt.

If solar engines are our last hope the sun and earth will be directly geared together. Mills will be attuned to a blazing star. The cold north where most of our coal is situated will all but lose its population. Once more the human race will migrate. The tropics will be invaded by capitalists who seek to establish textile mills, iron-works, chemical factories. A new metropolis will spring up in the South-west of the United States or in the Sahara Desert. Arid tropic land, rarely visited by rain, will command a high price. Yet not too high. Note that square miles must be considered when it comes to utilizing solar heat on a large scale.

The solar engine is driven by heat. What of the light that the sun sheds? That too is energy. Its effects are partly chemical. So we find that chemists have likewise concerned themselves with the problems of

saving our machine culture. Every green leaf bottles solar luminous energy. Even though less than 3 per cent. of all the radiance that beats on the earth is thus captured, the total is still enormous. A miracle happens. Gases of the atmosphere are changed into living cells composed in part of starch, sugar, and cellulose. Suppose that the process of growing could be accelerated so that a tree would visibly push its way up and up before our eyes and mature in days instead of decades. The world's fuel problem of a thousand years hence would be solved. Sugar and wood costing but a few shillings a ton would be one consequence.

Lastly there remains atomic energy as a possible saviour of our culture. Soon after radio-activity was discovered, physicists began to speculate on applying the energy that radium was radiating at a rate that could be measured. They determined that radium was breaking down into a succession of elements of which the last was lead. The whole process consumes centuries. Suppose we could hasten the decay of radium. Instead of a mere trickle of energy we would obtain a Niagara. Prof R. A. Millikan has disposed of these romantic possibilities. 'There is not enough radium at our disposal to run our popcorn-roasters,' according to his calculations.

But what of atomic energy? The late Lord Rutherford once said that 'the human race may trace its development from the discovery of a method of utilizing atomic energy.' And Aston, his pupil, listen to

ıim: 'If we could transmute hydrogen into helium ve should produce energy in quantities which, for any ensible amount of matter, are prodigious beyond the lreams of scientific fiction. . . . In a tumbler of water ies enough power to drive the *Mauretania* across the Atlantic and back.'

When Einstein published his theory of relativity the ıope of utilizing the energy within the atom again ame to life, this time in another form. Einstein howed that mass and energy are interchangeable. Energy can be converted into mass and mass into nergy. In transmuting hydrogen into helium, particles nust be added to both the nucleus and the electronic atmosphere' of the hydrogen. But the packing of the articles to effect this transmutation occurs not quite n accordance with the mathematical theory. Actually he packing is too tight. Something is left over. This xcess (four times 0·00778) would manifest itself, ccording to the Einsteinian doctrine, as energy. It is hus that the sun and the stars are able to radiate light nd heat for billions of years. But where are we to btain stellar pressures of millions of tons to the inch nd heat measured in millions of degrees? Prof Millikan made some calculations which convinced him that hough elements are built up in interstellar space in ccordance with the theory, it is impossible to duplicate the process on earth. Before the Society of Chemical Industry he delivered the verdict that 'there s not even a remote likelihood that men will ever tap his source of energy at all.' Thus vanished again the

dream of converting the hydrogen in a few gallons of water into helium and letting excess mass dissipate itself in energy so abundant that it could spin all the wheels of the world.

In January 1939 a discovery was made simultaneously in Europe and America which momentarily revived hope in the possibility of utilizing atomic energy. By means of neutrons which are given off by beryllium when it is bombarded and which are then slowed down, startling results are produced in uranium. These slow neutrons split the uranium atom. They move scarcely faster than the molecules of a gas, these neutrons, and convert uranium into rare actino-uranium, which is highly explosive. So unstable is this actino-uranium that it splits into two and in the process releases 200,000,000 volts of energy. The ratio of energy input to energy output is about ten million to one. Unfortunately there is no known way of practically obtaining enough pure actino-uranium, and if there were, the dissipation or waste of energy would be enormous. In a word, the process would be inefficient. Most of the energy required to form actino-uranium is spent in exciting the original uranium, and this is a dead loss in an engineering sense. So the problem of running the world's machines with energy from the atom must again be given up for the time being.

IX. The Chemical Revolution

From the advertisement of a New York department store:

Grandma got by with a new bonnet and a smear of talc across her pretty little nose—but times have changed. To make it easier for modern beauties we have assembled the Personal Spectrum Kit with all related cosmetics to suit your individual colouring.

From an article by Edsel Ford, exploiter of soya beans and builder of motor cars:

Our engineers tell us that soya-bean oil and meal are adaptable to by far the greater part of the many branches of the whole new plastic industry, and that shortly we are to see radio and other small cabinets, table-tops, flooring tiles in a thousand different colour-combinations, brackets and supports of a hundred varieties, spools and shuttles for the textile trades, buttons and many other things of everyday use all coming from the soya-bean fields.

From an address by the director of an industrial research laboratory:

In 1913 the most carefully made automobile of the day had a body to which twenty-one coats of paint and varnish were applied. By 1920, through scientific management, it was possible to do a body-painting job in about eleven days. In 1923 came the first nitro-cellulose lacquers. They cut the time to two days. Now a whole body is made out of metal and coated with any colour in a day.

From a German scientific magazine:

Over twenty-five years ago the German chemist Todtenhaupt patented a process to convert the casein of milk into artificial wool. Under the economic stress of the Ethiopian war the Italians developed the process and by October 1936 will produce several hundred thousand pounds annually of artificial wool. No one pretends that it is indistinguishable from natural wool. It is still imperfect, but no more imperfect than were the first fibres of artificial silk. It meets men's needs—all that can be reasonably demanded.

COSMETICS, SOYA-BEAN PRODUCTS, LACQUERS, CASEIN 'wool'—all are 'synthetic', as the term is somewhat loosely used nowadays. There are thousands more like them, transformations of such familiar raw material as coal, petroleum, wood, slaughterhouse refuse. Indeed, every article that we touch is a chemical product of some kind, and many a one has no counterpart in nature.

Despite a million chemical compounds known to technologists, despite the manifest artificiality of clothes, houses, vehicles, food—all the result of chemical progress—we have made but a beginning in the creation of a new environment. If the test of a culture based on science is the degree of its departure from nature—woven cloth instead of skins, gas in the kitchen instead of wood, electric lights instead of naked flames, rayon instead of silk—we are still chemical semi-barbarians.

It is beside the mark to argue that a culture consists of something more than plastic compounds that take the place of wood and metal. Our society is what it is just because the engineer and the chemist have struggled with nature, torn apart her coal, her trees, her beauty, discovered how they were created, and then proceeded to make new combinations of their own. The lilies of the field and the honey of the bee are not in themselves sufficient. On every hand there is synthesis and creation—scents, fabrics, drugs, plastics, metal like aluminium, sodium, and a few thousand alloys that nature forgot to make when the earth was a cooling but still glowing ball, dyes, unmatched by any gleam in the iridescent feathers of a peacock's tail, high explosives, lung-corroding gases, talking-machine records made of carbolic-acid derivatives or artificial resins.

More than the substitution of a synthetic for a natural product is involved. Buttons that look like ivory or bone but are neither, fibres that mimic silk but are better, automobile upholstery that passes for leather but is a form of guncotton, photographic films that bring the same screen-plays to tens of millions simultaneously for as little as a shilling—these are the outward evidences of a breaking down of social distinctions, of a profound change in life. Gunpowder made all men the same height, said Carlyle in a fine but unwitting comment on chemistry. The levelling is not yet ended.

New industries came with the rise of chemistry, and

with them new opportunities for the many. There is a closer relation between democracy and the laboratory than the historians recognize. The environment has been chemically changed, and with that change has come a new vision of the social future. Is the world ready?

Already a beginning has been made in three-dimensional chemistry. The potentialities are infinite, breathtaking. Suppose you want something as transparent as glass but as strong as metal. A three-dimensional chemistry may achieve it. There is even the possibility that active compounds may be devised—active in the sense that they would shrink from blows or electric shocks just as if they were alive.

Much so-called synthesis is merely a transformation of some natural product. Yet it is an evidence of social and scientific progress. It was a tremendous step from killing an animal and wearing its skin for protection to weaving a fibre on a deliberately invented loom, and thus making a soft pliable fabric. But the fibres were nature's after all.

Indians once froze on ledges of coal. Mankind leaped ahead when inventors showed how coal could be used to raise steam and drive an engine. But the new conception of coal is chemical. It is a conception of cosmetics, alcohol, drugs, strange artificial sugars, a million useful compounds. So with wood. It is no longer a material out of which tables and chairs and houses are built, but cellulose, which can be reconstructed to assume the form of shimmering, silk-like

filaments, cattle-fodder, explosives.

Economists speak of the stupendous change brought about in the world by the steam-engine as the 'industrial revolution'. And what a revolution it was! Factories sprang up in every civilized country. The age of power had dawned. Coal assumed the importance of a priceless national resource. The mechanical engineer became a dominant factor in a civilization based on the utilization of the energy in coal. He had 'harnessed heat' and transformed the earth.

Today we are in the throes of what has been called the 'chemical revolution', a revolution which will perhaps be as wide-sweeping in its effects as the steam revolution that began a century ago. The stuff of which the universe is composed is being torn apart, molecule by molecule, atom by atom; and out of the atomic fragments new kinds of matter are being created and the release of a new kind of energy is promised.

Perhaps the most imminent of all the changes that the chemical revolution will bring about will affect the materials of engineering. This age of power also is the age of steel. Age of rust would be a better designation. If it were not for our paints and protective coatings nothing would be left of this machine civilization a hundred years hence. No less an authority than Sir Robert Hadfield has estimated that 29,000,000 tons of steel rust away every year at a cost to mankind of £280,000,000. And this is not all. To produce every pound of this metal, lost by conversion into oxide. four

pounds of coal had to be burned. The chemical revolution has already ushered in the age of alloys, many of them non-corrosive. There are 2000 of them, and we have hardly begun to create all that the world needs. Parts of gasolene engines are now made of aluminium alloys. All-metal airplanes have for years been made of duraluminium—a strong, tough, artificial metal. Aluminium alloys can be made as strong as steel. Very rapidly they are making their way in industry.

What a tremendous amount of energy is wasted in hauling, lifting, and spinning unnecessarily heavy masses of metal! It costs now threepence a pound a year to move the dead weight of a street-car. Think of the solid steel trains hauled by solid steel locomotives, of automobiles made largely of steel, of cranes that must be made of tremendous size and power to lift gigantic masses of steel machinery! Tradition has obsessed us with the notion that weight and strength are synonymous. Gradually the metallurgist is breaking down this old conservatism.

Ten thousand years ago, indeed until very recently, the metallurgist was a random smelter and mixer of metals. Bronze was one of his magnificent accidental discoveries. But how different today! With X-rays he peers right into the heart of a crystal—for nearly everything in the crust of the earth is crystalline—and sees how the atoms are placed. He juggles temperatures—relates them to such properties as toughness, magnetism, lightness. He makes a mixture of aluminium, nickel, and copper. The result is a magnet that can

lift a hundred times its own weight or an alloy so light that stratosphere balloon gondolas are made of it.

Already he has reached the stage where he can synthesize a metal for a special purpose. Suppose he were to design and build an alloy with five times the tensile limit of any we now have—not a wild impossibility. When he succeeds, ' the art of transportation on land and sea will be revolutionized and, unfortunately, the methods of warfare,' thinks Dr Vannevar Bush of the Massachusetts Institute of Technology.

Many of these alloys still to be discovered will be used in the home. Wood as a structural material is already doomed. Two centuries hence an ordinary white-pine kitchen chair of today will be treasured as an almost priceless antique. Quarried stone will be used only for buildings near the quarry. For the most part our houses will be cages of rustless alloy steel, around which cement or some other artificial plastic material will be poured.

Furniture will be made of a beautiful synthetic plastic material, a combination of carbolic acid and formaldehyde discovered and first applied industrially by a Belgian chemist, Dr L. H. Baekeland, which is destined to become so cheap that it will compete with wood. The panes of the windows through which sunlight streams and the glassware that glitters on the carbolic-acid-formaldehyde sideboard will be made of a scratch-proof synthetic product of organic chemistry which will be transparent, insoluble in water, and unbreakable.

Draperies, rugs, bed and table 'linen' by the year 2000 will be tissues of synthetic fibres. Washing will be obsolete. Bed-sheets, table-cloths, and napkins will be thrown away after use. Draperies and rugs will not be cleaned, for as soon as they show signs of dirt or wear new ones will take their places. The household of the chemical future will probably spend no more in a year for its fabrics than it does now for mere laundering. Hence housework will be reduced to a pleasant minimum involving scarcely more than the dusting of synthetic furniture and the mopping of synthetic floors.

Even dish-washing will be unnecessary. By A.D. 2000 the chemist will have discovered a method of making bowls, cups, saucers and plates out of a compound which will dissolve in water superheated to a temperature of 300 degrees Fahrenheit. The 'china' or 'porcelain', after serving its purpose, will be tossed into a superheating cooker to dissolve like sugar in tea and run down a drain. Soluble dishes of artistic design will cost only a few pence each. Their dissolving temperature must be higher than that of boiling water, so that even a scalding hot soup can be served without fear of disaster. Hence the superheating. Only knives and forks and pots and pans will be scoured—if these relics of the quaint past are still used.

Synthetic, too, will be the apparel of those who will live this easy life. Cotton, silk, wool and such fibres as linen will still be spun, but only the very rich or the very snobbish will buy the fabrics into which they are

woven. Such material will be as unnecessary as are the expensive furs in which fashionable men and women still clothe themselves—mere survivals of a picturesque time when animals had to be skinned or clipped to make a suit of clothes. Already the silkworm is doomed as an adjunct of industry. Time was when only the worm knew how to change the woody tissues, or cellulose, of a tree into glossy threads. Now the chemist converts the tree into rayon and even makes silk, or something very like it, out of coal, limestone, and nitrogen.

Synthetic wool is a commercial reality. The achievement was inevitable. Perhaps within ten years, certainly within twenty, a man will buy a ready-made suit of synthetic wool as warm as any now made from natural wool, and free from shoddy, and £2 will be a high price to pay for it. Even the most knowing sheep would be deceived by the yarn. There will be the same 'feel', the same fluffiness and waviness.

This £2 suit is almost attainable now. In the more distant future synthetic fibres still to be evolved will completely revolutionize tailoring. The cheapest suit of clothes is now stitched. What if machines do most of the sewing and if buttonholes are mechanically formed and finished? The cost is high. Suppose we assign to the chemist and the efficiency engineer this problem of keeping the body warm and the person presentable. The first step is to abandon the old tradition of durability. Why must even the cheapest suit last at least a year? Is not the standard merely a heri-

tage from a time when money was scarce and when a suit of clothes simply had to endure?

The synthetic chemist proceeds to create new fibres. Cheapness is his goal. His threads may be lacking in tensile strength and therefore in durability. But the fabric into which they are woven is not intended to last a year. Something much cheaper than artificial silk or wool is produced. In fact, it is so cheap that a suit can be made for five shillings—a suit that will be as ephemeral as a butterfly and will be thrown into the ash-barrel in two weeks.

You step into a department store of 1975 and say: 'I want a spring suit. Something in grey—striped.'

The salesman disappears. He comes back, not with a suit, but with pieces of a suit. You look them over with a critical eye. 'Rather neat,' you decide. A fitter is summoned. He drapes the pieces upon you and then proceeds to paste them together—yes, paste—so that you receive for five shillings what is actually a custom-made suit. The paste is another triumph of chemistry—a composition which makes it impossible to rip seams apart without destroying the fabric itself. And the suit fits as if the tailor of nobility had fashioned it. Why pasting instead of stitching? Because stitching, even machine stitching, is an unnecessary expense, a heritage of tradition.

The fibres are the chemist's contribution to tailoring of 1975; the method of stamping out pieces of the right shape at a single stroke of a die, to be pasted

together later, is the efficiency engineer's. Two dozen perfectly fitted suits a year at a total cost of £5. Beau Brummell could demand no more.

So it will be with cravats, socks, handkerchiefs, and shoes. From head to foot the glass of fashion of 1975 will dazzle the Avenue, a living tribute to the ingenuity of the synthetic chemist. The very cane that he twirls will be synthetic, and so will be the diamond (indistinguishable from a South African crystal) that flashes on his finger. Only a few laundries will survive to charge outrageous prices for washing the linen of a handful of rich old mossbacks who, so far as the eye can tell, might be wearing synthetic fabrics instead of real stitched wool, silk, flax, or cotton.

Rags will be unknown and inexcusable. The beggars of 1975 will be quite as presentable as stockbrokers, actors, and others who set store by the cut and the fit of their coats and trousers. Indeed, in the chemical millennium it is possible that a workless man may implore a passer-by not for the price of the customary cup of coffee but for the price of a suit of clothes.

The synthetically clad man of the future will surely nourish himself on synthetic food. Ultimately even the soluble dish will be regarded as an interesting heirloom of a still fairly savage past when man chewed vegetation which had been boiled or baked, and actually killed and roasted animals for the sake of their proteins. But the year 2000 seems much too early a date for the achievement of synthetic nutriment,

considering the staggering difficulties that the chemist must overcome.

Marcellin Berthelot, the great French synthetic chemist, predicted an era when man would eat three food pellets instead of three meals a day. Physicians who are good evolutionists know better. Teeth, jaws, digestive tract, the whole organism of man, have been ingeniously adapted to convert plant and animal tissues into bodily energy. There is evidence enough that subsistence on preserved foods is attended with ills with which savages are never afflicted. It is said that the Eskimos never knew what the toothache was until they ate the food of the white explorers. For the simple reason that man was constructed to thrive on natural rather than on synthetic food, it is not likely that he will live on pellets. The chemist will give him the bulk and the texture to which his digestive tract long ago adapted itself.

Probably the chemist's first achievement in synthesizing a food will be the commercial creation of sugar. A beginning has been made in our time by Prof E. C. C. Baly of the University of Liverpool. He knows that green plants will not produce sugar from carbon dioxide and water unless light is present. There must be what the chemist calls 'photosynthesis', the most fundamental process in all organic nature. The sap of a plant, largely water, itself a compound of hydrogen and oxygen, rises from the roots to the leaves; the green colouring matter of the leaves (chlorophyll) takes the hydrogen of this water and

combines it with the carbon of the carbon dioxide into what the chemist calls a carbohydrate, a chemical combination of carbon, hydrogen, and oxygen. One such carbohydrate is sugar. Out of nothing but light, water and carbon a green leaf produces it.

Prof Baly, knowing this fact, proceeds to imitate nature. In his Liverpool laboratory are dazzling electric lamps—artificial suns. Also there are quartz vessels through which invisible ultra-violet rays emitted by the lamps pass, acting chemically on the contents of the vessels. And the contents? Largely water in which carbon dioxide is dissolved. Finely powdered iron, nickel, and aluminium compounds are added to the water—catalysts, or substances which take no part in the chemical action, but provide a large surface on which the action can take place. The ultra-violet rays from the artificial suns are turned on the vessels, and a syrupy carbohydrate is obtained. Analysis reveals it to be sugar.

The light works the miracle, as Prof Baly has proved to his satisfaction over and over again. He performed the experiment hundreds of times in the dark. Never could he synthesize sugar without light. In nature the photosynthesis of carbohydrates is associated with the green colouring matter of leaves; the chlorophyll is probably a catalyst. To mimic nature with greater fidelity, Prof Baly went so far as to use coloured catalysts, such as the carbonates of cobalt and nickel. Again sugar was synthesized—this time with the aid of visible rays.

Here we have the primitive beginning of a future synthetic sugar and starch industry, of something akin to a life-process. The raw materials are abundant and cheap. Instead of carbon dioxide, of which the atmosphere contains but little, the chemist will use coal. Water he finds everywhere. Catalysts he uses over and over again. Instead of ploughing the soil and cultivating sugar-beets, the farmer will watch pressure-gauges or control the ultra-violet lamps of some synthetic food corporation. Nature produces many varieties of sugar. The chemist will make them all out of water and carbon. Just as he has succeeded in giving us dyes that have no natural counterparts, so he will give us sugars that nature never dreamed of making.

The achievement of the synthetic equivalent of a hen's egg or a slice of roast beef will be immensely more difficult. We must learn how to build up proteins. A great German chemist, Emil Fischer, did more than any other scientist of our time to throw light on this most difficult of all duplications of the life-process, and won the Nobel prize for his work. The protein of an egg or of roast beef is a highly complex compound of nitrogen, carbon, hydrogen, sulphur, and oxygen. Fischer succeeded in breaking down albuminoids (compounds which have some of the properties of albumin and hence of protein) and then rebuilding something like them out of the units. But only something like them. He obtained what are known as synthetic peptides, which resemble natural

albumins in many respects. In the opinion of the late Prof Abel of Johns Hopkins, 'the contributions of Emil Fischer surpass in their ultimate significance for chemical physiology those ever made by any other man in the entire history of biological and medical science.'

To nine out of ten of us a chemist such as Fischer is still something of a magician, a mysterious figure, impelled to mix together strange and sometimes dangerous compounds, only to discover that he has at his command an explosive that will blast mountains asunder or a plastic that is a substitute for wood. But the chemist knows better. He deals with such invisibilities as atoms and molecules exactly as if they were levers and gears. In his mind's eye he sees them assembling themselves into new structures. He deliberately plans new forms of matter as an architect plans a house or an engineer a streamlined train.

Contrast, for example, the organic chemist of a century ago with his university-trained counterpart of today. Goodyear comes to mind. 'Discovered how to vulcanize rubber,' we say of him with a certain awe. He boiled, pounded, kneaded rubber, mixed it with scores of different substances, exposed it to sunlight and kept it in darkness, and at last achieved success in vulcanization by frying it in a pan with sulphur. There is less of this floundering today. Like the architect and the engineer, the chemist is now a conscious designer—a designer of molecules, of new forms of matter.

The picture that the chemist draws of an arrangement of atoms in a molecule may not be absolutely correct. But it must be a practical help. The fact that it does help is an indication that it must be at least approximately right.

Executing the design is not so easy as conceiving it. Sometimes the atoms can be arranged in the desired way only at impossibly high temperature and pressure; sometimes there would be explosions. Contemplating nature with a technical eye, what does the chemist see? These trees, animals, sweet-smelling perfumes, these poisons that the reptiles and insects secrete, all these she has made without fierce temperatures, tons of corroding acids and alkalis, or powerful electric currents. Even the vetches and beans of the field reduce nitrogen from the air without terrific heat or stout vessels of steel.

So the chemist must perforce limit himself, like the architect, to what can be accomplished with available materials and forces. Marcellin Berthelot once remarked: 'The domain in which chemical synthesis exercises its creative power is vaster than that of nature herself.' While this is undoubtedly true, still chemists have to batter down atomic gates. Nature opens them with a key.

X. *Can the Laboratory Create Life?*

LIFE WAS ONCE REGARDED AS A PURELY CHEMICAL manifestation of matter. Now it is recognized that forces are at play within and without the cell which enable it to adapt itself in a limited degree to its environment.

No one man made this discovery. But because of it, as Prof F. G. Donnan has pointed out, 'the day is nearer when the physicist will be able to create life, and there is no reason why life on a physico-chemical plane should not be constructed by the creation of living cells.'

This daring statement is based largely on some remarkable studies which Prof A. V. Hill made of the chemical part played by oxygen in muscular activity. He found that five-eighths of a horse-power can be exerted in such efforts as rowing. A gallon of oxygen supplies the rower (if used with 25 per cent. efficiency) with enough energy to lift his own weight of 140 pounds about 125 feet. But the heart and lungs can supply at most a gallon of oxygen a minute.

Nature has made it possible for man to overload himself for short periods by emergency chemical processes. Glycogen, the animal starch of the body, is converted into lactic acid—the very acid found in sour milk. Thus huge amounts of energy are released. But the formation of lactic acids is accompanied by fatigue. So the panting rower rests. As he inhales oxygen deeply, he rids himself of the lactic acid and hence of fatigue.

How much muscular work a man can do is deter-

mined by what Prof Hill calls the 'amount of oxygen debt' that can be incurred. Four or five quarts of oxygen is about the debt limit of most athletes, and fifteen means physical collapse. There is no guessing about this. Breathing in oxygen and eating food to supply energy are common to all animals. Hill has even measured the oxygen consumption of the cockroach and determined its 'debt'. Not only that, but he has ground the cockroach up and analysed its tissues to discover what changes have taken place.

Muscular tissue is composed of cells that incur and discharge the oxygen debt. Hence Donnan has commented thus on Hill's work: 'If you deprive the living cell of oxygen or food it dies and begins at once to go to pieces. Why is this? What is cellular death? The atoms and molecules are still there. . . . Has some vital impulse escaped unobserved?'

The more philosophers and scientists discover about life the clearer their definitions become, even though they are still turbid. For centuries they talked about 'vital force'. Mere words. 'Biotic energy' is no better. Even the great Huxley spoke of 'some kind of matter common to all living things' (another form of what biologists call 'vitalism') and imbued science with the notion that protoplasm is 'living protein'.

There is an almost medieval ring to these theories for all the learned words in which they are expressed. 'Elixir of life', the phrase bandied about when America was discovered, is just as 'scientific' as 'biotic energy'. Yet that half-quack, half-scientist, Paracelsus,

divined that ' man is a chemical composition, for which reason it is necessary to use chemical means to combat disease.' Not a bad guess for the early sixteenth century. But Paracelsus had to spoil it by advocating a charlatan's formula for creating the 'vital spirit' in an alembic.

That we must look for some undiscovered force or compound instead of new energy relations is a view that dies hard. Prof Henry Fairfield Osborn wondered whether there may not be 'some unknown element which thus far has not betrayed itself in chemical analysis', and which may be the life-giving principle —an element like radium, which was concealed in rocks for ages before the chemist became aware of it. ' Or again, some unknown chemical element to which the hypothetical term bion might be given may lie waiting discovery within this complex of known elements. Or an unknown source of energy may be active here.' We recognize 'vitalism' and the 'elixir of life', even though they are well disguised in modern verbal clothes. The chemist makes short work of any plea for a belief in unknown elements. He knows exactly how many elements there are and their properties.

We live. Yet who among us can say what life is? We walk, talk, grow, reproduce our kind, and die. The rocks are not like us in these respects. Five thousand years of study has not yet made it possible to define life. Streets and houses were illuminated by electricity long before engineers knew that a current

is composed of countless billions of electrons. Definitions are therefore not absolutely indispensable in the onward sweep of science.

On the other hand, engineers knew exactly what a generator was and how it should be constructed in order to produce current that would light a lamp or drive a trolley-car. In other words, they knew all that was necessary to make an electric generator—knew the attributes and functions of each part. Little is known about life-generators, and that is one reason why science is still baffled by the mystery of life. The more simple animal and plant forms are studied, the deeper is this mystery. Enumerating the functions of the simplest living organism and then insisting that a structure is alive if it performs these functions is useless.

To be alive a thing must move spontaneously, you say. A locomotive does that. If you must have something less complex drop some chloroform on a hardened shellac surface. The drop moves about like an amoeba. 'Surface tension! ' exclaims the chemist. 'The force that enables some insects to walk on water and causes rain to collect in globules on a waterproofed cloth.' Probably it is this same surface tension that makes the living amoeba so restless.

But the amoeba eats by the simple process of wrapping itself around its meal. Lifeless matter cannot eat, it may be argued. Can't it? Bring a drop of chloroform near a glass particle coated with shellac. Something extraordinary happens. The drop flows around

the particle, devours it, digests the shellac and then, most wonderful of all, actually rejects the indigestible glass particle! A living amoeba can do no more.

Hard pressed by these performances of lifeless matter, we remember that animals and plants grow. Surely lifeless matter does not grow. Throw a lump of copper sulphate into a dilute solution of potassium ferrocyanide. A brown envelope develops. It throws out upward-growing runners. In half an hour the solution is filled with a 'plant' that closely resembles seaweed—something that has grown in a very real sense. The weight of the artificial plant may be 150 times that of the original copper sulphate. Dozens of inorganic crystals thus grow and reproduce their kind. Like any living thing they need but a supply of the requisite pabulum. Even the process of self-division whereby a simple cell reproduces itself can be mimicked with solutions of common table-salt containing suspended carbon particles.

So the biochemist runs the gamut of the supposedly exclusive attributes of life only to find that 'dead' matter may have them, too, although not all at the same time. Herbert Spencer realized this. Yet he could not resist the temptation to define 'life' as 'the continuous adjustment of internal relations to external relations'. This has a fine impressiveness that carries conviction. When we find out what the terms actually mean we discover that the electric refrigerator in the kitchen meets them perfectly. The temperature rises. At once the motor starts automatically when the tem-

perature within the refrigerator has dropped below the critical point. The thermostat by which the motor is controlled is ever ready to adjust internal to external relations.

Now this inability of the biochemist to tell us what life is proves that we cannot be sure that we always recognize life when we see it. There is no sharp distinction between the organic and the inorganic, between the living and the non-living. Atoms are combined into molecules and molecules into such elaborate structures as salt and starch, cane-sugar or man. All matter has evolved and is still evolving from the simple to the complex. Hence Prof T. C. Chamberlin reasoned that there must have been an unbroken series of evolving organisms from the first cell that was endowed with life to a Ph.D.

Nature may be still busily creating life and causing it to evolve in ways of which we are not yet aware. She may be making scores of experiments in an attempt to evolve life from lifeless matter. If there are no fossil records of these attempts it is because they never progressed far enough.

Since the creation of life was no sudden animation of something inert but a gradual process of change from a mass of gas, a rock, a clod, through a stage between the animate and the inanimate to the living slime that we call protoplasm, there are biologists enough who believe that science ought to seek in nature for transitional forms of life.

It may be easier to synthesize near-life than to

recognize it as such in some noisome, slippery mass gathered on the shore of a lake. In the laboratory the condition of experiment can be controlled. For this reason alone the efforts of the biochemist to solve the riddle of life by synthesizing something that will physically and chemically resemble an irritable, hungry, restless, self-reproducing cell are more than justified. Hand in hand with laboratory attempts at synthesizing living matter must go a profounder study of nature —the quest for something which seems animate, yet which cannot be accepted as completely animate.

Even when the biologist asserts dogmatically that the lowest form of life is protoplasm and that every simple cell has a nucleus, he is not as precise as he thinks he is. Once upon a time chemists explained that iron rusted because iron had an 'affinity' for oxygen, which was no more a scientific explanation of what actually happened than if they had more simply said, 'iron and oxygen fall passionately in love with each other and cannot be kept apart.' By giving the name 'protoplasm' to a slimy mass which is composed of individual living cells and calling the dense core of each cell a 'nucleus' we simply identify objects for scientific study. We shed no light on the dark mystery of life.

'All life comes from life' has been an accepted doctrine in science for two centuries. Yet there was certainly a time when the earth was too hot to support life. Clearly nature must have succeeded in accomplishing what the biochemist is attempting now—to create

life out of matter that is not alive. So the ambitions of our scientific Frankensteins are not as mad and vaunting as they seem to be at first glance.

Consider the simplest protoplasmic cell under the microscope—a protozoon. Reproduction is simple. The cell simply splits in two and each new cell again in two. The process can go on for ever. 'The cell is immortal,' declared Weismann decades ago. So it seems. Prof Woodruff has watched a simple organism called paramecium reproduce itself by self-division through 9000 generations in thirteen and one-half years—comparable with 250,000 years of human life.

Combine several billion body and germ cells to form what the chemist calls a closed system. It turns out to be a human being. Its parents christen it John Wright. One day you read in the newspaper that something sensational happened to this closed system: 'Died, John Wright at his home after a brief illness. Age 64. Funeral private. No flowers.'

What actually happened? Why should he die when he was composed of immortal cells? The best we can wring from science is that John Wright began to die when he was a baby. Every day he threw off useless cells and useless molecules which he had broken down into stuff that he could use and into wastes. In fact, he had to die thus in order to live. If he managed to reach the age of 64 it was because he built new cells faster than he killed them. The day came when the doctor pronounced him dead.

Of course, the doctor was wrong. The cells of the

human heart have been revived and the heart caused to beat regularly eighteen hours after doctors have signed a death-certificate. In some lower animals the same result has been obtained days after 'death'. John Wright was not scientifically dead until the last living cell of him found it impossible to feed itself, extract energy from something outside of itself, and divide in two to reproduce itself.

John Wright's complexity proved to be his undoing. The price of being able to invent telescopes, look through them and discover that Jupiter has nine moons, of writing *Hamlet*, of composing the Ninth Symphony, or painting 'La Gioconda' is death. To Carrel it is a price worth paying. 'The mysterious energy which is created by the cerebral cells or which expresses itself through them is after all the greatest marvel of this universe,' he says.

To Metchnikoff old age was a disease. The experiments of Carrel support the view. His famous chicken heart is immortal only because its cells feed on young embryonic matter and because the wastes it throws off are washed away. On old plasma heart-tissue does not thrive so well. It seems as if old organisms do produce some substance which saps their vigour and that ageing is indeed a disease. So it seems that the 'elixir of life' for which science has been seeking these many centuries is actually the elixir of youth.

If we understand death we understand life. Hence the case of John Wright is of supreme importance to the biologist and the scientist who seeks to create life.

Death is a biological event. If only we knew what happens when a cell dies or is killed we would know what life is. That is why biologists are as much concerned with dying as with living. They seek to discover why the individual cells of John Wright are deathless, yet he as an individuality dies. If more were known about deathless protoplasm it might be possible to prolong human life.

By reducing the breeding temperature from 30 to 10 degrees centigrade Jacques Loeb prolonged the life of fruit-flies 90 per cent. He estimated that if he could lower the temperature of the human body to 7·5 degrees centigrade, human life could be extended 1900 years. John Wright was a chemical complex. His life was short and merry, because he was hot. Human beings are not fruit-flies. Their temperatures cannot be raised and lowered sharply. But Loeb proved that death can be staved off if we can control only one of the conditions of life. He went far towards proving that protoplasm is a name for a chemical and physical mechanism—that life can be controlled in lower organisms just as we can control any simple chemical reaction.

Before a living cell can be created in the laboratory the chemist must know much more. As yet he can no more define protoplasm than he can define life. Simple as it may appear under the microscope, a protozoon is nevertheless a microcosm which is far more complex than a dynamo or a grand-piano.

Within the cell are bodies of many different types, and each has a definite function. The biochemist does not know what the functions are. Some of the bodies are alive and others are not. Even the lifeless play some part in the tiny organism. What part? The answer is silence. The biologist cannot point to any part of a microphotograph which shows a cell enlarged several hundred times and say positively: 'This is the very seat of life, the shrine of shrines.' In fact, all the evidence indicates that life is a property of the cell as a whole, a complex of innumerable chemical and physical reactions in a system.

Suppose we attempt to construct a cell. First of all, we must find out of what a cell is composed. We analyse protoplasm just as we would water or a rock, only the task is much more difficult. What does the analysis show? Oxygen 72 per cent., carbon 13·5 per cent., hydrogen 9·1 per cent., nitrogen 2·5 per cent. There are also traces of chlorine, phosphorus, sulphur, sodium, calcium, silicon, iron, manganese, iodine, magnesium, and fluorine. Protoplasm is composed of much the same stuff as the earth itself—evidence that it sprang from the earth. We mix all these chemical components together in just the right proportions. And the result? A laboratory mud-pie. Not a sign of life. Nothing that even remotely resembles protoplasm as an organism. Life cannot be compounded like a drug-store prescription.

A colloid chemist looks over the mass with a disapproving eye. 'A cell is a colloidal system,' he remarks.

What does he mean by a colloidal system? A crystal of any common mineral salt when dissolved will pass through a thin animal membrane. Were it not for that membrane its contents, mineral salts among them, would work their way through as a result of what is called osmosis. It is not enough to mix the proper elements together in the right proportions. The molecules must also be of the right size. Then surface tension must be exerted to hold this aggregation of molecules together within the thin wall.

The colloid chemist has introduced physics into the problem. We begin all over again. This time we manage to make tiny cells filled with the proper chemical elements in proper combination. We look through the microscope. We see movement. For a moment it looks as if these infinitesimal artificial organisms lived. Then we remember the drop of chloroform that slipped about on hard shellac with such deceptive, realistic spontaneity. What we behold is surface tension at work, pushing cells hither and thither. We have not created life after all. We look more closely. There is no nucleus and no such distribution of bodies through the whole mass as we observe it in a protozoon. Besides, the cell refuses to split and form other cells like itself.

Another expert is called in—a fermentation chemist. 'You ought to learn something about enzymes if you want to be a Frankenstein,' is his devastating criticism. You inquire about enzymes and you find out that they are bodies which have the peculiar property

of bringing about chemical reactions in living matter but without appearing in the final product. Enzymes are, therefore, catalysts. Hydrochloric acid can act as a catalyst, for it will reduce cane-sugar to glucose and fructose. At the end there will be just as much hydrochloric acid as before, ready to break down a new batch of sugar.

The commonest enzyme-catalyst of all is zymase, produced by yeast. It is the zymase that enables yeast to make quick work of fermenting sugar to alcohol and carbon dioxide. In a cell enzymes are for ever building up and breaking down compounds, thus aiding in the process we call living. There are many enzymes, and each performs one particular task only. Just as a key fits only one lock, so a given enzyme acts only on a given substance.

There is little use in continuing the Frankensteinian experiment. Not enough is known about enzymes. They have much to do with converting the food that a cell eats into energy. Like a boiler and a steam-engine, a cell traffics in energy. Coal is potential energy; so is the food on which cells and human beings thrive. The crudest kind of synthetic life, even cruder than protoplasm, will perhaps prove to be an organic compound which will absorb energy from the outside with the aid of a few enzymes and give up carbon dioxide, very much as if it were a microscopic boiler furnace.

Baffling as are the difficulties that confront the scientist who seeks to penetrate the secret of life, they may be no more formidable than those which

physical chemists had to overcome before they could discover that the atom, so far from being the smallest unit of matter, is in itself a system composed of a nucleus and of outer electrons. X-rays and radioactivity were the clues that led to the formation of the electron theory. Possibly some new discovery may be made about protoplasm, some undivined attribute, which will lead the biochemist to frame a new theory of life. 'The mystery of life will always remain,' comments Prof Donnan. So will the mystery of matter, he might add, despite all the proof that has been accumulated that electrons are realities and that matter and electricity are one.

Life is energy. The atom is energy. If mathematics and physical chemistry can tear away the veil that once enshrouded the mystery of the atom's source of energy, what may they not do for the exact interpretation of life? They will enable the biochemist to see the molecules in protoplasm in their proper relationships, to understand better than he does now the functions of the enzymes, surface tension, and other forces that govern the life of a cell, and to specify on paper just how he must go about the business of synthesizing the lowest form of cellular life.

The distinction between life and non-life is not what it once was. In fact, it has even been proposed that we should call an atom alive when it is excited—when, for example, it is radiating light. So we find L. L. Whyte, an English physicist, boldly envisaging the construction of a synthetic living organism in

accordance with the precepts of the electron theory, largely for the purpose of laying bare the nature of the problem and the necessity of allowing for the time element.

'Could an infinitely wise physicist order the necessary chemicals today and tomorrow put together a synthetic man?' he asks. 'If not, why not?'

He invites us to watch the physicist at work. In a few moments the physicist has prepared some simple molecules from their elements. 'Now he has completed the first colloid that he will require, and is starting on his first organic synthesis. But this infinite wisdom does not give him eternity within a minute, and we notice that he is getting on more slowly. While the actual combination of the first molecules took only about a thousandth of a second, once he had the apparatus ready the simplest colloid took about a second. The organic colloid took about a minute; it seems that nature won't work faster than that. She has her own rhythm and won't be rushed. If we wait patiently till the end of the day our friend may have his first speck of protoplasm, and all the skill in the world would only have helped him to make more of it, not to have got any further in his game of evolution.

'But look at him now! He is making a hasty calculation, as though he just realized some great secret of nature, and knew that he could never create his homunculus.' And Whyte gives us the imaginary physicist's table of the estimated minimum time

required by the synthetic processes of nature to attain various evolutionary stages as follows:

Simple organic compound	1/1000 second
Simple colloid	1 second
Protein	1 hour
Primitive protoplasm	1 month
Simplest unicellular organism	10 years
Flagellate	1000 years
Mammal, including *Homo sapiens*	1,000,000 years

Whyte uses the table to point the moral that every chemical reaction, whether it involves non-living or living matter, requires time; and the greater the number of atoms that have to settle down together into some special arrangement, the greater must be the time allowed. A laboratory-made man is unthinkable. The best that the physiological chemist can do is to create some very low form of life, control its environment for many generations, and let evolution take its course.

If man is ever evolved under laboratory glass in this fashion, hundreds of thousands of years must elapse. The times given by Whyte, moreover, are theoretical minima. The period required for evolution to attain its end is at best a shrewd guess. 'Only an International Institute of Evolutionary Research under the most stable League of Nations could hope to create an artificial man, and even then man could hardly take the credit, for time would have done more than man,' says Whyte.

So the best for which we can hope is the creation

of simplest unicellular organisms in a theoretical minimum of ten years. But what excitement when that first bit of animate albuminous matter begins to move, to show signs of life! Telegraph and radio will flash the news over all the world. On the front page of every newspaper will appear the startling headline: 'Life Created in Laboratory!' And how that artificial bit of life will be watched! No royal baby could be cared for with more devotion. How it takes its meals, how its behaviour indicates its general well-being, will be discussed at every breakfast-table. Chemists will analyse the 'soup' in which it lives to make sure that it will not be starved to death and that it will not be poisoned. And when it splits up into two and thus carries out the simplest of all processes of reproduction, there will be more broadcasting, more headlines, more learned, scientific monographs. Chemistry will have achieved its greatest triumph.

XI. Evolution since Darwin

ON SEPTEMBER 16, 1835, CHARLES DARWIN LANDED FROM the warship *Beagle* on the Chatham Islands in the Galápagos Archipelago, which lies some 500-odd miles west of America under the Equator. ' By far the most important event in my life,' he wrote in his notebook, the one which 'has determined my whole career'.

It was in the Galápagos that Darwin saw the great truth of evolution unfolded — the dovetailing of species and varieties into one grand scheme which embraced the lowliest things that grow and crawl and the highest type of civilized man. The theory of natural selection had still to be developed, but the train of thought that led to it had been started.

Biology has undoubtedly expanded since the *Beagle* made her famous voyage; it has become more and more an experimental science. Mendel's laws of heredity provide a working formula for the plant and animal breeder. Chromosomes and genes have been discovered—the counterparts in biology of molecules and atoms in chemistry. Mutations (variations from existing species) have been artificially produced. Lastly, the mathematician has entered the field and thrown a flood of light on the manner in which species sustain themselves in the struggle for existence and in which they survive. What has been the effect on Darwin's doctrine? Where does the theory of natural selection stand today?

If evolution is a fact, something must make an animal or plant evolve. Lamarck decided that it must be looked for in the animal or plant itself. He thought

that organisms must respond to an inner impulse or urge of some kind. A fowl takes to water because of new necessities or opportunities and tries to paddle. The urge for webbed feet is thus aroused. Not only this, but the tendency towards webbing, the desire to paddle, would be not only transmitted but intensified. 'Use inheritance' is the technical name for the process. There is also a 'disuse inheritance'.

Darwin arrived at a different conception. He had studied the ways of breeders. In fact, he did some experimenting with plants on his own account. Always there was variation from the parents. But there was also close resemblance. Strong, heavy draught horses sprang from strong, heavy sires and dams. The breeders saw to that and deliberately prevented what were to them mismatings. So with pigs, sheep, cattle, and dogs. 'Artificial selection', Darwin called the process. Was there a similar ruthless weeding out of undesirable plants and animals in the forest and the sea? He read Malthus, and the truth flashed on him.

Malthus presented evidence to show that populations increase more rapidly than the food supply. Hence there must be starvation and death. Who starves and dies? Naturally the weak. Populations must therefore reach a point of equilibrium. Is a similar influence at work in nature? Even a slow-breeding animal like the elephant would overrun the earth if death did not intervene to cut him off. Lack of food, physical defects, any one of a hundred unfavourable traits might prove to be his undoing. Un-

favourable for what? Life in the jungle. Very subtly and imperceptibly, then, nature was selecting the fit. Each generation was thus mercilessly put to the test. Only the right variation of an elephant, parrot, mosquito, oak or grass could survive.

The contrast between the conceptions of Lamarck and Darwin is evident. According to Lamarck, a creature must will and strive to evolve; according to Darwin it must do or die. Haeckel saw no inconsistency in the two views and dedicated his *History of Creation* to both Lamarck and Darwin. And even the great Darwin himself accepted 'use inheritance' as a partial explanation of the process of evolution whenever it suited his purpose.

Before we can appraise Darwin we must understand what he meant by natural selection. He decided that new species arose through random variation—the appearance of some slight peculiarity which was not found in the parents and which was transmitted to later generations. Did natural selection cause the species to vary? Or did it simply test chance variations and peculiarities and destroy those that were unsuitable to the environment, such as legless lions or eyeless insects?

The Origin of Species is one of the clearest books on a new theory ever written. Yet it is difficult to discover just how Darwin thought that new species originated. The variations had to be slight, and they had to occur at random. Sometimes he meant variations that are bodily differences, known to be without significance

in evolution (like the hothouse forcing that produces large grapes), and sometimes differences that were the result of some inner urge like that pictured by Lamarck. When it came to explaining how natural selection, the struggle for existence, could both choke off the unfit and initiate new species, he could speak but vaguely of 'a strong principle of inheritance'.

There is virtually no evidence that weeding out the unfit creates anything in nature. A reaping-machine cannot account for the sprouting of new grass or the direction in which it will grow or the shape of its blades. There is no solid proof that the mere struggle for existence, unless we invoke the discredited Lamarck, can launch a change.

An experimental biologist of our day could raise at least a hundred pertinent objections to the theory of natural selection. Among the more important would be these:

First—Some species have died out in one place but not in other places. In the absence of any change in the environment, why should this be so?

Second—There is no relationship between the lethal factors (disease, weather, enemies) and advantageous qualities. Death strikes at the adapted and unadapted indifferently. Dewar, a naturalist who studied the selective elimination of birds in India, reached this conclusion: 'The individuals which survive longest in the struggle for existence are the lucky ones rather than the most fit.'

Third—The differences supposed to account for

survival are not sufficiently of the life-and-death kind. It is nonsense to pretend that a bird will refuse to eat a worm which is just beginning to acquire a bad taste. So with the case for mimicry. The departure must be marked to be of any use. If it is too marked it usually does not survive.

Fourth—Variations may be harmful or worthless in the struggle for existence. Why are they not killed off promptly? Why, for instance, did nature take the trouble to evolve unwieldy dinosaurs over countless centuries?

Fifth—Natural selection ought to be reversible when the environment reverses. The phenomenon has not yet been observed.

Sixth—Only slight variations are supposed to play an important part in evolution. Where is the positive proof that this is so?

Seventh—The time when death occurs is usually ignored by natural selectionists. Natural selection must take its toll at a suitable age. But do selective deaths occur at the right age?

Eighth—If variation is a random process, as Darwin assumed, the origin of a variation can have no relation to its survival value.

Ninth—Evolution, according to Darwin, involves variation and survival. To say that chance variations survive because they have been selected is merely to say that they have survived. It is variation that must be explained.

Tenth—Natural selection implicitly assumes what it

sets out to explain—that continuous inheritable variation occurs constantly in all directions, which it does not.

We are left exactly where we were when Lamarck and Darwin were in their heyday—left asking ourselves: Exactly how did the infinite variety of life come about? How is one species transformed into another? This is the real issue.

Huxley, Darwin's most ardent and able champion, told his master that the lack of experimental proof was the weakest point in his case. And Darwin himself once wrote to Huxley: 'If, as I must think, external conditions produce little effect, what the devil determines each particular variation?'

We want precisely the kind of experimentation that has made physics and chemistry exact sciences. Not until we see variations springing into being, not until we actually bring them about in the laboratory under control, not until we behold with our own eyes one species evolving into another, can we deduce what has happened to the fishes of the sea, the birds of the air, the four-footed creatures of the forest in past geological eras.

While Darwin was startling the world with his theory of natural selection, an obscure Austrian monk, the Abbé Gregor Mendel, was actually resorting to this very method of experiment. Darwin might have altered his views had he known of the work.

The monk grew sweet-peas in his garden, crossed them this way and that under the strictest control, and

at last formulated the now famous Mendelian laws of heredity. He presented his discovery in a paper read before an obscure society in Brünn, in 1865. In the transactions of that body it slumbered for thirty-five years—until the beginning of the present century. Then de Vries in the Netherlands, Correns in Germany, and Tschermak in Austria independently and almost simultaneously formulated the same laws after conducting breeding experiments.

It was de Vries who first developed the discovery of the manner in which variations are transmitted. The evidence showed that the variations—mutants, in technical parlance—appear suddenly. Intransigent Darwinians were dazed. They had been taught to believe that there was nothing sudden about the processes of evolution. To be sure de Vries saw in this nothing inconsistent with natural selection and remained a staunch adherent of Darwin all his life.

After the effect of the first shock had worn off, and more experimenting had been conducted, it turned out that the variations or mutations were promptly killed off if they were too marked. Nature has no use for monstrosities. Only the slightly abnormal plants and animals survive, breed true, and transmit the abnormalities. Back we are again to Darwin. He may have been right in holding that only the small differences count. But he was wrong in thinking that evolution is a continuous process involving all the members of a generation.

In Darwin's time most naturalists were convinced

that noses and eyes, arms and legs were inherited as such—that cabbages and kings transmitted themselves as whole collections of features and parts. After the revolution brought about by the rediscovery of Mendel's laws and the work of de Vries, Correns, Tschermak, Bateson, Cuénot, Morgan, and scores of other hard-headed pragmatists, it was evident that a living body is built up like a house from given materials in accordance with an invisible set of blue-prints. The changes that do occur in plants and animals are dictated by what happens in the egg.

Weismann, one of Darwin's staunchest adherents, suspected all this. So did Darwin, for that matter, if we read some of his definitions of variation correctly. Weismann chopped off rats' tails for scores of generations. But always the tails grew in the offspring. He performed other experiments which showed that no matter how an organism was mutilated the effect was nil on subsequent generations. So he preached the doctrine of germ plasm—the doctrine that the germ cells or eggs are not the product of the body in which they are found but of the germ cells or eggs of the previous generation.

Within the cells Weismann and others saw little bodies now called 'chromosomes'—literally 'colour bodies'—because they can be easily stained and thus made visible under the microscope. But the chromosomes were not the ultimate units. Within the chromosomes lie the real determiners. Like the atom the determiners of new varieties must be inferred. They

cannot be seen even with the most powerful microscope. Genes they are called.

With the inspiration of genius Thomas Hunt Morgan decided to experiment with the now famous *Drosophila melanogaster*, a fruit-fly that breeds a new generation every nine days. In a single year he could study twenty-five generations or the equivalent of 500 years of human family life. If germ plasm could be modified, fruit-flies would tell the story in their aberrations from their ancestors.

With a patience buoyed only by the stimulus of a great idea, Morgan bred flies by the millions and kept a carefully indexed *Almanach de Gotha* of their children and their children's children. No human family is as sure of its ancestry as he is of his fruit-flies' progenitors. He and his school examined more than 20,000,000 flies and found about 400 mutants that bred true. Today more than 600 mutants are known.

Morgan assumed that the genes of the male chromosomes exactly matched the genes of the female chromosomes. Thus the genes that control wing shape in one chromosome lie opposite the corresponding genes in the other chromosome. So with the matching genes that determine eye colour, length of hair, and the hundreds of other attributes of a fruit-fly, a bird, a cow, a man. Genes crossed over from one chromosome to the other, the children receiving them from both father and mother. At last it became apparent why children are so like their parents. And crossing

and recrossing also explained why children depart from their grandparents.

In the process attributes can be combined in different ways. So we inherit from our parents not noses and eyes as we inherit real estate or money—the belief in Darwin's time—but genes. There can be no doubt of their existence. There must be 2000 to 2500, then, strung along like beads, each different from every other in a string, each playing its own rôle in the highly complicated economy of the cell.

But not yet had it been proved experimentally that the genes are actually the units of heredity. There now began ingenious efforts to jolt the genes—change their constitution and arrangement. The experimenters tried everything—drugging, poisoning, intoxication, anaesthetics, bright lights, utter darkness, suffocation, whirling in centrifugal machines, mechanical shaking, mutilation, heating, chilling, starving, overfeeding. In vain.

Then Prof H. J. Muller decided to adopt the methods of the atomic physicists. If, he reasoned, X-rays can tear an electron from an atom and thus convert it into so very excited a bit of matter that it glows, what if they were turned on the genes?

The result was startling. What actually happened is not yet clear. Apparently the genes were either changed chemically or shifted out of their places—perhaps both. Instead of 400 mutants in 20,000,000 Muller got 150 times as many. He had accelerated the evolutionary process 15,000 per cent. And what mon-

strosities! Flies with eyes that bulged, flies with eyes that were sunken; flies with purple, white, green, brown, and yellow eyes; flies with hair that was curly, ruffled, parted, fine, coarse; flies that were bald; flies with extra legs or antennae or no legs or antennae; flies with wings of every conceivable shape or with virtually no wings at all; big flies and little flies; active flies and sluggish flies; sterile flies and fertile flies.

What had happened? 'The roots of life—the genes—had indeed been struck and had yielded,' in the words of Muller. Could there be any doubt after this that genes exist? Or that the method whereby the differences that distinguish one generation of organisms from its predecessors are inherited is at last revealed? Or that differences in genes do arise suddenly to bring about large variations?

The problem of evolution narrows down to the gene. We are now at the rock-bottom of life, but still unable to explain how new species originate. There is reason to suppose that the genes are simply highly complex chemical substances. This merely shifts the direction of inquiry and speculation. How did these substances, these genes, come together? Through accident or design? If they are mere chemicals, how is it that they change and perpetuate themselves, whereas iron, gold, other matter, on the whole remain what they are?

The next step is to fathom the chemistry of the gene. Not until that is done will the evolutionary process become clearer and such terms as 'acquired

characters', 'use inheritance', 'natural selection', 'survival of the fit', 'struggle for existence', be stripped of their mysticism. We have only been romancing in what we thought was a scientific fashion and, by giving names to mysterious activities, deceiving ourselves into believing that we understood them.

Already it is evident that the problem of the gene is the problem of the atom. This being so, the physicist who studies the constitution of matter and the biochemist who studies genes and why they vary chemically and thus give rise to new forms of life, will ultimately find themselves confronted by the same phenomena. For the problem of the evolutionary process is not merely the problem of life. It is the problem of the cosmos itself.

XII. Carrel

AMID EIGHTEEN LINDBERGH PERFUSION PUMPS IN THE Rockefeller Institute for Medical Research, each enclosing a vital organ or piece of tissue, officiates Dr Alexis Carrel, high priest of biology. White-clad women enter, glance at a pump occasionally, cast a practised eye on a living morsel, and leave. They look like nurses, act like nurses. In fact, this room is a hospital, a new type of hospital, where livers, spleens, kidneys and ovaries are patients.

Born at Sainte-Foy-lès-Lyon, in France, Carrel was only seventeen when he was graduated with a bachelor's degree at the University of Lyons. He turned at once to medicine and received his M.D. from the university's medical school in 1900. Fables were told of his surgical dexterity even in his student days. One of them which attributes to him the ability to tie knots in a match-box with three fingers makes him laugh.

'Even if I could perform this trick there are women among my assistants who can do better,' he comments. 'With a needle they can split a sheet of paper into two sheets without tearing it.'

At any rate, his experience and knowledge was such that he was invited to join the faculty of the University of Chicago in 1905. A year later he entered the Rockefeller Institute for Medical Research. There the rest of his work has been done, with the exception of that in the war years, which found him in charge of a base hospital at Compiègne, in France, not only saving lives with the famous Carrel-Dakin solution

but also studying the healing of wounds and fractures.

Behind Carrel lies forty years of ruminating on life, of glimpsing it in its simplest forms through microscopes, of incredibly delicate surgical operations on tissues and organs. He has travelled far. His unrivalled skill, his ingenious techniques have achieved triumphs that would have seemed as wildly incredible to the men who taught him biology and surgery in the University of Lyons as a medieval tale of some alchemist's homunculus seems to us.

Curiosity is supposed to be the driving force of science. No doubt it is. But 'curiosity', as we use the term, implies a toying with instruments and materials as if the scientist did no more than say: 'Now let's fire protons at lithium with a million volts and see what happens.' Much science is necessarily of that kind. But not Carrel's. For more than forty years his has had but one purpose, but one direction. From the beginning he decided that he would study life as life and not infer what he could about it from death—lifeless cells, bloodless muscles. Or, as he puts it, 'structure and function are one and inseparable.'

The man who reasoned and wrote most eloquently and effectively about the futility of reaching sound conclusions about life from mere meat, either in the mass or in minute transparent slices studied under a microscope, was the great French physiologist Claude Bernard. A living animal is not merely a collection of cells and organs, each with a structure and function

of its own, he taught. It is a whole, a beautifully integrated mechanism. Bernard insisted that every organ has its 'internal milieu'. Structure, function, environment, these are a unity. They should be studied as a unity. Schwann, the German, said the same about the cell. A gutted fish on the kitchen table is not the same fish that once swam in water. So with excised tissues and organs.

Carrel was eighteen when Bernard's conception of the internal environment illuminated everything and crystallized his own doubts about the validity of classical biology's methods. A new approach was needed. Surgery, chemistry, physics, cytology, medicine, anatomy—twenty sciences must be welded into one science to study a living thing, whether an organ or an animal.

To be convinced that the traditional approach was wrong is one thing; to evolve the techniques of a new one, another. Carrel began with wounds and fractures as a medical student. He was struck by the fact that dressings only keep out bacteria. They have no direct influence on the healing process. Why do some wounds and fractures close and knit more rapidly than others?

He became interested in surgery. As a surgeon he had to study blood-vessels. From blood-vessels he passed on to the mechanism of healing. Even then he thought it might be possible to cut out tissues, keep them alive, transplant them successfully to a medium which would be the equivalent of the old environ-

ment. And then substitute facts for theories and speculations.

His experiments led him to the conclusion that toxic wastes must be removed—wastes that poison—if cells and tissues are to be kept alive. That conclusion was to be strengthened in later years. Then he read of Prof Ross Harrison's work at Yale—great work that caused the scales to fall from biological eyes all over the world. That was in 1908.

Harrison wanted to know whether nerve fibres grow only out of nerve cells in the spinal cord or whether they can grow from any cells in the body. He dissected a few nerve cells from the spinal cord of an embryo tadpole. With the utmost precaution against infection he put them in a drop of the clear part of frog's blood and sealed the whole in a minute glass chamber which he could scrutinize under a microscope. Before his eyes the nerve fibres grew out of the nerve cells. The conclusion was obvious. The nerves that make a big toe twitch have grown several feet from a cell in the spinal cord near the hip. Tissue culture was born as a science.

Carrel was deeply impressed. Here was Claude Bernard's dream become a reality. A little nerve cell in the right environment could be studied alive for a few hours, just as if it were in the body. It was a triumph of technique. Carrel realized that he must become a better technician. Possibly he is the greatest technician of our time.

What technique means to Carrel may be gleaned

from the mere externals of his procedure. He robes himself and his assistants in black to avoid reflections. Even the hoods that cover heads are black, revealing only the eyes. The room is windowless. No shadows are cast by the light overhead. Tables are draped in black cloths. Furniture is black. No hospital operating-room is so speckless, so dustless, so germless.

Imagine him back in January 1912. He takes a nine-day-old fertilized egg from an incubator, washes it, sterilizes it, cautiously cracks the shell, lifts out the unborn chick, lays it on a sterile base, skilfully excises its fleck of a beating heart. How long can it live outside of the body in the right medium?

The environment is ready. Days before he had prepared it. Embryonic chicken juice. He had cut up, ground, mashed an embryo until he had a pulp, and then he had mixed the pulp with a solution of salt to preserve it. Next he had whirled the juice out of the mixture just as cream is whirled out of milk in a centrifugal separator.

Snipping off a bit of heart only eight-hundredths of an inch square, he transfers it with a certain preciosity to a drop of clotted, but clear, chicken-blood plasma. An additional drop of embryonic juice and the speck of heart is left to itself, properly protected. The tissue has been encased in its environment. There structure and function can interplay.

Two days later the microscopic fleck has doubled in size. It is cut in two with a blade only a tenth of an inch long and is bathed to wash away the killing

wastes. Quickly the retained bit of tissue is transferred to a new drop of plasma incorporated with fresh embryonic juice.

The culture lives on and on to prove that cells need not die if they are fed and their wastes are removed. Nurses trained by Carrel watch over the culture. It has its microscopic ailments. Perhaps it needs a bath; perhaps a change of diet; perhaps a period of fasting. The vestal virgins who guard this living flame know. A hundred years hence their descendants may also be standing over the culture, performing the same surgical and aseptic rites. It may be destined to survive an indefinite number of attendants.

There is something frightening about the way the cells grow by self-division. In a year a microscopic bit of heart would be thirteen quadrillion times bigger than the sun if half the growth were not cut away and if it were theoretically possible to keep all cells alive as they divide and divide and divide. The excretions that kill seem a blessing.

In no other laboratory has this exploit been repeated over a period of time so long. The explanation is technical perfection, unflagging vigilance, the utmost refinement in asepsis. As for the embryonic chicken juice, biologists regard it as a stroke of genius. It was as natural to Carrel to think of it as it is to think of water as the only world in which a fish can live. Is it not part of the natural environment?

Nothing reveals the quality of Carrel's mind better than the lessons that he draws from his seemingly

immortal culture. It grows but does not age. With organs it is different. With them more than mere growth is involved. Chemical changes take place in the internal environment, the fluids that feed and bathe. Ageing is part of an organ's life.

What, then, is time? This is a very practical question to Carrel. He speaks of 'physiological time', which has nothing in common with the absolute time ticked off by the clock or marked by the calendar. We feel it ourselves. To a boy, time drags; to an old man, it flies. It is inseparable from life.

To drive home the significance of physiological time Carrel refers to the experiments made by the late Prof Jacques Loeb of the Rockefeller Institute. That eminent biologist hatched fruit-flies and kept specimens of the same batch at different temperatures. At 50 degrees Fahrenheit, about the temperature of the lower part of a kitchen refrigerator, flies lived 177 days, or nearly six months; at room temperature (68 degrees), 54 days; at 86 degrees, only 21 days.

Age as a function of absolute time means nothing in interpreting these varying spans of life. How old were these three groups of flies in terms of their own bodies? The batch kept at low temperature was still young long after the high-temperature batch had flourished and died. Just as relativists treat time as a fourth dimension and speak of space-time, so Carrel speaks of growth-time or life-time. Growth, life are part of time. Is time part of the environment?

To a man who thinks thus, a successful experiment

with a segment of chicken heart is only a beginning. The culture told nothing about the time-process, nothing about growing old, because it did not grow old itself. Whole living organs would have to be studied in especially invented glass bodies.

Long before Colonel Lindbergh appeared on the scene Carrel had begun to experiment with so-called 'heart pumps', highly ingenious inventions of the instrument-makers of the Rockefeller Institute. They were not wholly satisfactory. It seemed impossible to keep out the germs that kill.

The Colonel turned up at the Rockefeller Institute —brought there by Dr Paluel Flagg, perhaps the foremost anaesthetist in the country, organizer of the Society for the Prevention of Asphyxial Death, the man who was Mrs Lindbergh's anaesthetist when her first child was born. Lindbergh saw perfusion pumps at work splashing 'blood' over organs, learned how hard it is to keep out bacteria, asked intelligent questions.

Carrel has his own way of judging human beings by a process of intuition which is beyond describing. Some current of understanding passed between the biologist and the aviator. Carrel cannot explain what happened. He was impressed by the Colonel; the Colonel by him. From that moment perfusion pumps became as much an obsession with the Colonel as airplanes.

The perfusion pump consists of three superposed glass chambers. In the top one rests the organ to be

studied. A liquid, which is both food and blood, is rhythmically splashed over the organ by air-pressure, collected by the central chamber, where the pressure is equalized, and then permitted to run back to a reservoir chamber. Compressed air furnishes the driving force of the operative mechanism. A rotary valve causes the air to act on the liquid pulses. There are no moving parts other than the valve.

The organ needs 'air' as well as blood. Hence gases are supplied. To keep out germs the tubes through which they pass are stuffed with cotton. What the system of heart and lungs still needs is some way to remove wastes, a sort of artificial kidney. When that is devised it will probably be possible to keep organs in glass much longer than the present thirty days.

It is difficult to estimate the value of the Colonel's contribution to Carrel's crowning achievement. Carrel gives him all the credit.

There is no doubt about the success of the Colonel's pump. Hundreds of organs have been kept alive within its sterile glass bulbs from two to thirty days—hearts, lungs, livers, spleens, reproductive organs. The hearts beat on, the glands secrete hormones, organs function just as they do within the bodies from which they were dissected. Here is the culmination of forty years of experimenting, self-perfection, philosophizing. Some day it may be possible to repeat the success of the chicken heart on a higher scale and to behold a kidney or a pancreas secreting fluids long beyond

the span of a human life. Alexander's dust stopping a bung-hole? Why not his heart beating on for ever?

'Medical engineering' this new development may be called. It is of as much importance in the progress of medicine as Pasteur's discoveries. Pathology is at present only a descriptive science. It tells what has happened to a tissue or an organ—not how or why anything happened. The time has come to experiment with living organs as if they were carburettors or differentials in an automobile. Carrel himself modifies the chemical composition of the 'blood' that circulates within the glass 'body' of a thyroid or kidney—adds insulin, adrenalin, hormones, and sees how the chemical and physical activity of the organ responds. Claude Bernard's dream is realized in a small way. Vital organs and their environment are studied together as units.

How do the thyroids, pituitary, pineal, adrenals, and other glands secrete the hormones that differentiate us from one another—determine whether we shall be idiots or geniuses, giants or dwarfs, men or women, dynamos of energy or sloths? There is hope of answering, now that glands can be observed at work. What is the relation of heart to kidneys, of ovaries to milk-producing breasts, of one organ to another? How do organs degenerate when they are attacked by disease? The pathologist of the future may watch the progress of Bright's disease, of tuberculosis in a piece of lung, of endocarditis in a heart, of arteries hardening.

At last the process of ageing can be studied in blood and tissues. Carrel has already convinced himself that if only we can rid ourselves of toxic products most of us may hope to live a century and more. It may take fifteen years, a generation, perhaps longer, to accumulate the facts that medicine needs. The end must be not only new ways of protecting the human organism against disease, but also positive ways of improving the quality of tissues and blood. Carrel once told the New York Academy of Medicine that some day it may be possible to put men in hibernating storage, activate them, return them to storage, so that they may live several centuries. 'The Utopias of today are the realities of tomorrow.' He wants an institute dedicated to the process of ageing—the investigation of the chemical, physical, and physiological changes that take place from the cradle to the grave, especially in the blood.

But Carrel has an outlook far wider than that of a medical engineer. All his life he has been a synthetic philosopher. To him man cannot be understood merely by understanding how his cells, tissues, and organs interact. Mind has hardly been touched. It is part of the body, not a separate entity. The separation of mind and body—the old duality of Descartes—sweeps it away. To Carrel it is as meaningless as a side of beef hanging from a hook, so far as explaining the process of living is concerned. Yes, mind and body are one. And the environment is part of the unity, just as blood is part of any organ. Why not include the

universe? A synthesis which embraces the outer nebulae and the human kidney, cells and cities, thyroid glands and totalitarianism—that might satisfy Carrel.

He looks at man with hope rather than disapproval, but is sure that we have misdirected our inquiries. It is not enough for science to give us health and comfort. Our progress has been made in machines rather than in men. Our science is too analytic. It tears man apart and hands pieces of him over to the specialists — chemists, anatomists, pathologists, ethnologists, psychologists, physicists, physiologists. He thinks that we cannot progress much farther in this way. Look at the result. We have health and comfort. We have created an extraordinary, artificial environment for man which has had terrible effects. But man—no one has attempted to change him yet. So we behold Carrel plunging into sociology as well as a study of tissues, organs, and environments. Nothing short of a superman with a supersoul will do for him. Especially important is the supersoul. Hence his preoccupation with religion, telepathy, and matters at which most scientists look askance. Where man is concerned, everything matters to Carrel.

The physicists and some philosophers dismiss all this as metaphysical moonshine. His achievements speak for themselves. The piece of chicken heart that lives on in the Rockefeller Institute, a proof that cells and environment, structure and function, cannot be separated—that came out of moonshine. The organs

that live thirty days in Lindbergh's pump and again prove the unity of structure and function and environment—that, too, came out of moonshine. Let us have more moonshine.

XIII. *Man and His World*

MAN RUSHES THROUGH THE AIR IN PASSENGER PLANES AT speeds of more than 150 miles an hour and dreams of rocket ships that will whisk him across the Atlantic between breakfast and luncheon. He rises miles into the stratosphere, where oxygen must be inhaled from a tank if he is to retain consciousness. He drills and blasts for gold in South Africa in a gallery dank with the steam of hot springs, and in steel-mills he handles metal which is so much liquid fire. He huddles in cities of stone and steel, there to fall a prey to germs of which he knew nothing in his primitive hunting life of a few thousand years ago. Upon his eyes and his ears sights and sounds impinge that wear down his nerves. He creates an artificial environment for himself and in it lives an artificial life. Clothes, lights, rooms, plumbing, steam-heat, cooked food, dishes, knives and forks, even the atmosphere in an air-conditioned theatre, hotel, or ship—everything is artificial. He is as much a forced product as a hothouse grape. Can this primitive savage, who only ten thousand years ago kept body and soul together by trapping and stoning forest animals and spearing fish, stand the nervous strain of the machine world that he has fashioned for himself? Ever since Darwin's day physiologists and anatomists have had their doubts. Latterly the doubts are more audible than ever.

At a recent congress of the American College of Surgeons, Dr R. C. Buerki, past president of the American Hospital Association, presented a picture of

this modern man, a victim of high blood-pressure, enlarged heart, failing circulation, jangled nerves—afflictions brought about by inventions that make it possible to do several things at the same time, such as gulping down more food in five minutes than a Zulu can gather in a day and listening to broadcast jazz or reading a newspaper. And in a course of the Terry lectures delivered at Yale the Nobel prize-winner, Sir Joseph Barcroft, showed how delicate is the balance between mind and body and how quickly the mind succumbs when the conditions under which the body naturally thrives are only slightly changed. At the 1936 meeting of the British Association for the Advancement of Science the distinguished palaeontologist Prof H. L. Hawkins dubbed man 'the only irrational creature'. And at the Harvard Tercentenary the specialists in nervous disorders made it plain that the pace set by our machines is too fast for the harassed organism.

The glory and the curse of man are his brain. It raises him above the beasts of the field and the forest, but it also dooms him as a species. For that brain of his is overdeveloped, overspecialized. It endows him with a mind that conceives new machines to take the place of muscles, new instruments to supplement inadequate senses, new and more complex ways of living in communities. The poor body cannot adapt itself rapidly enough to the social and technical changes conceived by the mind. Heart and muscles belong to the jungle; the modern mind to an environment of its own crea-

tion. The verdict seems to be that man must crack under the strain.

First we consider the story told by the fossil bones of creatures that once possessed the earth and then vanished. They scream Cassandra prophecies.

'We developed now this organ and now that to secure an advantage over our enemies in the struggle for existence,' they warn. 'See how some of us increased our speed, others waxed stronger and larger, and still others practised the art of mimicry in adapting ourselves to the environment. All in vain. One by one we perished.'

They ask ominous questions—these bones. 'Where are the first things that crawled out of the sea? Where are the pterodactyls—hugest creatures that ever flew? Where are the dinosaurs that once shook the earth? Where are the common ancestors of apes and men? Where, for that matter, are the first, crude men of Java, China, Rhodesia, and England, the half-apes that ruled the forest a million years ago? Where are the Neanderthalers and Cro-Magnons of only fifty thousand years ago?'

The bones preach sermons on the virtues of simplicity. On the whole it is the simple organisms that endure—the one-celled organisms best of all. These are not brilliant, clever specialists, but biological jacks-of-all-trades. Not that complexity and specialization are necessarily fatal. They are merely highly dangerous. The lowly things are harmonious wholes. Introduce specialization—a more efficient way of

gathering and devouring food, a surer hold on a rock or tree, a nervous system more responsive to the dangers of the environment—and the old harmony is impaired, the road to extinction cleared. When man learned how to use his mind, more was involved than the mere development of reasoning power. Stories have been written by Wells and others of super-intellectual ants that defeated man and assumed ascendancy. Good fiction, but bad biology. Man had to pass through a creepy, slimy, slithery, finny, furry past before he could acquire his complex central nervous system and his brain. He came out of the oyster and the starfish, the shark and the tiger, the cow and something from which he and the ape sprang.

Each upward step was marked by an important physical change—a better co-ordination of mind and body. The foot and the hand of a chimpanzee, man's nearest lower relative, are different in structure and even in function from our feet and hands. Jaws, brow, teeth are different in structure, too. Adapting himself to an upright position, acquiring the art of walking on two feet instead of four, making a clutching and holding tool of the hand—all this was accompanied by the evolution of the brain, the most complicated single piece of apparatus in the world.

Apparently this rise from the oyster is not yet ended. Moreover, it has not been a uniform process. Sometimes it was this organ that shot ahead, sometimes that. The central nervous system, of which the brain is the vertex, has outstripped all else. Man is an

overspecialized animal by reason of his brain. And it is overspecialization that dooms him to ultimate extinction.

Surveying man with a critical eye, the late Prof Elie Metchnikoff of the Pasteur Institute found him anything but the piece of work that Hamlet held up for admiration. What is the good of hair? asked the Russian derogator. It catches germs; it is a vestige of the ape within us. Look at the caecum (blind gut, in yeoman's English) and the large intestine. Utterly useless. Mere cesspools. Cut them out, was Metchnikoff's advice—surgical operations actually performed with success. Then there is the eye. We might overlook the optical mistakes made in its design and construction if only it would maintain its efficiency. At forty-five the lens is already old. Walking on two feet has brought with it fallen arches, varicose veins; a now illogical distribution of valves in the circulatory system, congested livers and a hundred other lapses from physical perfection. Man as a social animal needs correction and improvement. The surgeon is helpless. Speed up evolution, was the conclusion reached by the great Russian rebel against nature. Unless that is done man must fall a victim to his own brain and works.

The strain upon the nervous system is as nothing compared with that to come if the engineers and inventors maintain the present pace. Utopians like Prof H. J. Muller predict that each of us will some day be in potentially immediate communication with everyone on earth. Can the race stand it? Even the

prospect of more speed terrifies a physiologist such as Barcroft. 'What of the accidents that befall aeronauts in pursuit of records?' he asks. 'It is the human element which gives way, and it is not the body of man but his mind.'

Metchnikoff is not alone. Anatomists, physiologists, palaeontologists agree with him on the whole. Listen to Sir Arthur Keith:

Beyond a doubt civilization is submitting the human body to a vast and critical experiment. Civilization has laid bare some of the weak points in the human body, but the conditions which have provoked them are not of nature's ordaining but of man's choosing.

And next to Dr Charles B. Davenport, geneticist of the Carnegie Institution of Washington:

Apparently man is to be compared with the great horny and armoured dinosaurs, the great elk, and many fossil nautili in which an exaggeration of a part was followed by extinction. . . .

Inherent laws of mutation and evolutionary change will work themselves out and man will in time go the way of all other species.

And lastly, Prof H. L. Hawkins, speaking in 1936 before the British Association for the Advancement of Science:

. . the high cerebral specialization that makes possible all these developments and the extraordinary rate at which success has been attained both point to the conclusion that this is a species destined to a spectacular rise and an equally spectacular fall, more complete and rapid than the world has yet seen.

Consider now the story told by the physiologist about a body attuned to the wilderness. For a moment limit yourself to the blood alone and see what happens to the mind when its physical and chemical balance is disturbed ever so slightly.

Overheat the blood, and you rave. Yet men must work nearly at the raving point in deep, steaming gold-mines, in hot boiler-rooms, at the mouths of blazing furnaces, to produce the things demanded in making an artificial environment.

Chill the blood, as Sir Joseph Barcroft did by lying naked in an icy room while an assistant watched. For a time the body tries to combat the cold. Barcroft's mind told him to get up, walk, keep his blood in circulation. But he refused for the sake of science. Then the mind gave up the battle. He stretched out his legs. He felt warm. ' It was as if I were basking in the cold,' he says. He was content to lie still, blissfully indifferent to a death from which his vigilant assistant saved him. His mind had ceased to watch over him.

Take away oxygen from the blood. The mind loses in reasoning ability. At 18,000 feet in the Andes, Barcroft and his assistants suffered from 'mountain

sickness'—a sign of oxygen deficiency. Not a man thought of inhaling oxygen from cylinders brought along for just such an emergency. Later in England Barcroft pedalled a stationary bicycle in a room from which oxygen was gradually withdrawn. He had planned to manipulate certain gas valves. Observers noted the mistakes that he made. Yet he was willing to swear in court that he had turned the handles correctly. His mind was beginning to crack.

So with the breathlessness that affects men who fly at great heights. They suffer not from an affection of the chest muscles, as they think, but of the nerves that control the muscles. The central nervous system has failed to perform its duty.

Decrease the calcium in the blood by half. Convulsions, coma, then death follow. Double the calcium. The blood thickens so that it can hardly flow. Heaviness, indifference, unconsciousness mark successive stages of the mind's dethronement. Again death is the end.

Reduce the amount of sugar in the blood ever so little. There is a feeling of 'goneness', at the worst a blotting out of the mind. Then death. Increase the sugar a few milligrams to the cubic centimetre and fear seizes the mind—fear of trifles. Double images form. Speech is thick. There are illusions.

Blood is slightly alkaline. Acidify it slightly. Coma follows, meaning that the mind is blank. Make the blood a little more alkaline. Convulsions foretell the end.

Take water from the blood. We collapse from weakness. Add water. We suffer from headaches, nausea, dizziness.

Change anything about the blood—the amount of oxygen, carbon dioxide, a score of chemicals—and always the mind gives way. The point is that some of the diseases that civilization has brought upon us do affect the physical and chemical constitution of the blood. Diabetes, for example. So the chemical analysis of the blood has become an almost indispensable aid in diagnosing many afflictions. And because it is indispensable it speaks eloquently of that downfall which palaeontologists predict.

It may be argued that we do not deliberately interfere with the organism as Barcroft did. But we do. Divers and tunnellers, for example, must work under high air-pressure. More gas is driven into the bloodstream. It cannot be without its physiological effect. 'No doubt,' says Barcroft, 'the thoughts of the human mind, its power to solve differential equations or to appreciate exquisite music involves some sort of physical or chemical pattern, which would be blurred in a milieu itself undergoing violent changes.' This means in plain English that a change in the environment—the kind of change that invention dictates—may be too much for body and hence for mind.

Prof Harlow Shapley, a zoologist who became the distinguished director of Harvard's astronomical observatory, once tellingly compared the ant with man. Both are social creatures. But the ant adapted itself

to its environment 360,000,000 years ago. Volcanoes have spewed lava, continents have split and floated apart, ice ages have come and gone, climates have changed, but the ant has emerged from each cataclysm unruffled and serene.

Today it is much the same ant that it was geological epochs ago. It is a highly specialized creature, this ant. But it subdivides its specialities—such matters as reproduction, working, fighting—among castes. And so it manages to strike a nice balance between its environment and its social self. It is all but stagnant in an evolutionary sense. But it seems to be permanent.

But man? An unstable thing. A dozen species of him have been evolved and destroyed in the last million years. He is an upstart compared with any social insect. He has changed his mode of community living time and time again in the last 25,000 years, but the ant's social organization has come down intact much as it was when the earth was younger. If survival is the test of fitness in the Darwinian sense, we ought not only to go to the ant and consider her ways but prostrate ourselves before her. Some day, as Shapley imagines, an ant will crawl out of the eye-socket of an extinct man and soliloquize: 'A marvellous experiment of nature's. What a brain! Alas, the poor creature did not understand the business of survival.'

There may be compensation in this rise and decline of man. If mere survival as a species is the *summum*

bonum, the ant is indeed the ideal social animal. To annihilate distance and time with airplanes and radio, to convert night into day with lamps that are miniature suns, to clothe oneself in fabrics woven from fibres that nature never knew, to see on the screen players who enact the events of a purely imaginary life—all this is beyond the unshakable ant. In us a mind that yearns is at work, but the reward of successful yearning is extinction.

Suppose that man does go the way of the dodo, the brontosaurus, and the sabre-toothed tiger. Is that the end of spirituality? Must the world relapse to mere savagery, just as magnificent cities of ancient Yucatan and India relapsed to the primeval jungle? Biologists as a class dislike the notion of purpose and direction in evolution. Yet it is hard to believe that life is 'but a disease of matter in its old age', as Sir James Jeans once hazarded in tracing the evolution of worlds.

Measured in terms of the brain, the trend of evolution has been up and on. Nature is willing to experiment with countless species, to toss them aside, as it did thousands of birds, fishes, and four-footed creatures, but in the end she sees to it that something better evolves. From her pitiless destruction of primordial half-apes and of such fine specimens of true humanity as the Cro-Magnons, it may be inferred that modern man is a poor thing in her eyes, ready even now for the scrap-heap. But something else will take his place if the past is any guide.

Perhaps we are only preliminary sketches, a prepa-

ration for some grander creature, a significant experiment in developing a spirituality higher than the tiger and the ape within us permit us to achieve. Perhaps extinction, the price of evolution, is not too high.

XIV. Jove's Competitors

IN THE EARLY DAYS OF ELECTRIC POWER, PUBLIC UTILITY companies stopped their machinery when a thunderstorm loomed because of the risk they ran from lightning. Interruptions were so common in some cities that they were not considered news unless trolley-cars stood motionless for at least a few hours. Most homes had combination gas and electric fixtures. Farmers' wives fortunate enough to have electric service were asked to pull the incoming power-switch lest lightning enter over the wires. Candles and oil lamps were kept for emergencies.

Although no central station of any importance now stops its machinery during an electric storm—such is the adequacy of the automatic circuit-breakers, oil switches and insulators introduced in the past few decades—lightning is still a menace, perhaps the only menace that the electrical engineer fears. In two years there were 4450 cases of damage by lightning to electrical apparatus in the experience of 165 public utility companies. With more than £160,000,000 spent annually for extensions of existing transmission and distribution systems and for interconnections required to carry out a vast super-power programme, the problem of lightning is of such economic consequence that industrial research was called upon to solve it.

Thus is to be explained the work that has been done for the past twenty-five years by the research engineers of the great electrical manufacturing companies. In elaborately equipped experimental stations record-breaking lightning-strokes of 10,000,000 volts

are generated, measured, and studied. Jove would nod approval, although the bolts that he hurls have an average of 100,000,000 volts.

With science compelled to watch these displays from afar, no wonder that it did much guessing about them, even after their electrical nature was established as the result of the practical tests proposed by Franklin. Only by studying lightning in the laboratory, only by handling it like ordinary current, is it possible to discover the most effective protection. But who can predict where lightning will strike? A man might wait for weeks in the open, with all his measuring apparatus, before his chance came. And so, like other engineers who are confronted here and abroad with the problem of protecting central stations, the research engineers decided to make their own lightning and to control the conditions under which it manifests itself.

Clouds above, earth below—charged with electricity of opposite sign. What could be simpler than nature's apparatus for the production of lightning? Electrons pile up until a cloud can hold no more. It is as if a boiler had burst under a pressure that cannot be resisted. Electrons are hurled between cloud and cloud or between cloud and earth in long, branching flashes. Over and over again the electrons are accumulated, and over and over again there is the same gradual increase of pressure—voltage, in engineering parlance—followed by explosions.

Remembering the majestic scale and the dramatic

setting of Jove's angry exhibitions, the preparations for a demonstration of man-made lightning necessarily suffer by comparison. A brick building which is part of a factory is no substitute for lowering skies and trees bending in the wind. Yet the General Electric Company's lightning laboratory at Pittsfield, Massachusetts, has an air of its own simply because it is so obviously electrical.

You enter the laboratory through a door marked 'Danger' in the most alarming shade of red that can be found, and you find yourself in an enormous cube of a room measuring more than a hundred feet square by seventy high. In vain you look for anything that resembles the mechanism of nature. Clouds? There are none. From the floor two huge wooden frames studded with shining brown insulators tower to a height of fifty feet. These, it seems, are the dams that hold back millions of volts until they are wanted. Among the insulators are little black boxes, so inconspicuous that you have to look hard for them. 'Capacitors', the engineers call the boxes. They are the 'clouds' of the laboratory. Within them the electrons are stored just as they are in the clouds that swim in the sky. They are very simple, these artificial clouds. Merely layers of lead-foil separated by insulating oil. The electrons collect on the foil and are spilled out much as they are in real clouds, except that they are under a certain control.

The current of electricity that lights our lamps and drives our vacuum-cleaners is a flow of electrons; and

a dynamo—an old-fashioned term now—is simply a generator of electrons, a sort of pump that forces them over wires. The engineer wants pressure, just as we want it in a pipe to carry water far. Pressure is expressed in volts. The more pressure, the higher the voltage. So the electrons from a dynamo or generator are passed through a transformer, which steps up the voltage. The process is much like that of reducing the size of a nozzle on a hose and thus obtaining a high-pressure jet of water. And from the transformers the electrons rush into the capacitors—the 'clouds'.

How conductive air may be depends on the humidity. It takes more volts, more pressure, to make lightning leap through dry than through wet air. That explains why strokes are rare in the Arctic regions, where the intense cold freezes out the water in the air, or in the desert of Sahara. The laboratory has a constant, artificial climate. There is just so much humidity—no more, no less. Since the amount of moisture in the air varies with the heat, the temperature is maintained at 70 degrees Fahrenheit.

The men in the laboratory deal not only with lightning of their own making but with death. Like the crew of a submarine, they obey a code of instructions, an engineering ritual. Everywhere are automatic switches. Unless the collapsible lazy-tongs gateway that bars the entrance to the laboratory latches and locks itself, the lightning apparatus cannot be started. On every hand are similar protective devices.

An electrician seats himself in a legless chair and straps himself in. From above, the hook of a travelling crane descends upon him. He slips it into a steel eye. In a trice he is lifted to the top of one of the frames. to make a few connections among the 'clouds'. Then he is lowered like a barrel of cement, as the crane travels down the length of its track, and neatly deposited on the floor just where he started.

The lightning is to flash between two points separated by about thirty feet in mid-air. A few electricians on the floor retreat to the walls and the corners far from the gap.

'Follow me,' says the engineer in charge.

He leads you up an iron staircase upon a balcony half-way between floor and ceiling. Orders are shouted. The lights are dimmed, the better to see the coming flash. And why not? Is there not always darkness before a thunderstorm? There is something ominous in the atmosphere. It is purely psychological and has nothing in common with the sultry quiet that precedes the fall of the first few large drops of a real storm. But there is the same sense of expectancy, the sense of an impending manifestation.

'It takes half a minute to charge the capacitors,' says the engineer, aware that you are wondering why nothing happens in this gloom. The storm is brewing, it seems, and the process is much like nature's, but more rapid. 'There will be a warning shout,' you are told, 'a few seconds before the flash.'

The shout is heard. The moment has come. You

stare straight ahead and wait—you know not quite for what. Then a blinding flash, a sharp, ear-splitting report. Darkness again. You are startled—awed. But the flash and the report are over so quickly that you scarcely know what happened. A terrific stroke has been delivered near you, and you have been spared because of the precautions taken in your behalf. There is a feeling of relief when the flash is over.

Technically untrained visitors expect something like the crash of real lightning. What they hear is the crack of a field-piece. There is no thunder—only just enough of an echo in the laboratory to suggest what happens among the clouds or in a valley when reverberations roll and roll. It is the engineer who is really overwhelmed. He knows that the energy in the flash is equal to that at the muzzles of six sixteen-inch naval guns.

Ten million volts go into that mighty effort. Never before has man made lightning on such a scale. When the largest spark passes—it can bridge a gap of sixty feet—65,000,000 horse-power leap through the air for a millionth of a second or so. Of course there is no generator on earth that can produce so much energy for even a minute. We deal here with a piling up of energy and its dissipation in a moment—with an electrical explosion in effect. The performance is so dramatically impressive not only because of the momentary, blinding glare and the gun-like crack, but because lightning has been reduced to an engineering basis. The voltage, or pressure, and the amperage, or

strength, is measured as accurately as ordinary mortals measure the passing of time by the clock.

'There will be another flash,' the engineer warns. The generator in the background is hard at work pumping more electrons into the artificial clouds—the capacitors—among the insulators on the wooden frames. Another shout from below. Again a flaming blade pierces the air, and again the ears are deafened with the report. So at intervals of a few minutes new electrical storms are brewed, and new searing flashes leap the gap in mid-air. And that pungent smell, very slightly suggestive of freshly sliced onions? Ozone. Even in the open, where the winds blow, it is noticeable after lightning has rent the air.

You discover something about your eyes that puzzles. You think you see the flash long after it has been extinguished. 'Retinal persistence,' explains your guide. 'It takes time to see anything, even though the time is but the minute fraction of a second, and it takes time to wipe out the image formed on the retina and telegraphed to the brain.' A good deal of imagination is probably at work when some claim to see the flash as long as half a minute after it has come and gone. The truth is that the stroke is seen after it has disappeared. Light travels about 100 feet in the time that the huge spark passes, and the distance of the eye from the gap is a little more than that.

What we have seen thus far may be compared with flashes that pass from cloud to cloud far above the

earth. The order is given to prepare for vertical strokes —the kind that splits trees to the roots. Again the electrician below takes his seat in his legless chair, and again the crane above drops a hook to lift him high among the 'clouds'. There he makes a few adjustments. On the floor below a telegraph-pole is set up. To guide the lightning to it a metal rod is placed upon it.

Once more the generator is started. A deafening crash. A vivid serpent strikes the metal rod on the telegraph-pole. There is a shower of splinters. Another flash. More splinters, some of them three feet long. Bolt after bolt is thus shot through the wood until the little that remains is as fuzzy as a brush. It is as if a mighty axe had cleft the wood from top to bottom. There is no sign of charring. Nor is there in a tree that has been split by lightning in the open. For the scientific interest of it, fires are set, conductors vaporized, explosions produced in water and oil. About everything is duplicated that nature does when she hurls a bolt from cloud to earth.

A dozen or more bolts flung at a miniature Empire State Building proved that the original acts as a perfect lightning rod, not only for itself but for all other buildings within a radius of 2·5 times its height if the threatening cloud is not too low. Verification has come over and over again when the building is struck during storms without the slightest damage. Those who sit at their desks in the offices never know that hundreds of millions of volts are dissipating them-

selves in the steel frame when the lightning crashes.

Out of such studies came a method of reducing the hazard of oil-storage tanks. Twenty million dollars' worth of oil was destroyed by fire in 1926 in Southern California. Now huge steel towers rise from 75 to 200 feet, each terminating in a piece of iron pipe tapered to a point. Each tower, like the Empire State Building, protects an area, and since the areas overlap there is reason to suppose that the tank district of Southern California is as safe as it can be made.

The longer the gap to be leaped, the higher must be the voltage. Luckily for man and his work, most lightning flashes are between 800 and 1500 feet long and, still more luckily, most of them pass from cloud to cloud. We have only to multiply each foot by 100,000 in order to arrive at the probable total voltage in lightning. Hence even an 800-foot flash represents a pressure of 80,000,000 volts.

Lightning is a pulsating discharge—a succession of strokes each of which lives and dies in a few millionths of a second. If there were a way of repeating the strokes over and over again we would have an arc. There is no way, but the result is no longer lightning. With the aid of a 2,000,000-volt alternating current generator (a machine that produces sixty complete cycles of oscillations a second in a circuit) a display is produced that shames the average Fourth of July celebration. In the darkened laboratory a weird violet glow appears on the wires. Corona, this is called. There is a hissing like that of high-pressure steam

from fine holes—a sign that the accumulating voltage is endeavouring to escape from each rough spot of metal. The wire points are arranged in the form of an open triangle, measuring nine and a half feet on each side. The points become the centre of the triangle, no longer violet now but brilliantly white. Louder and louder become the hissing and the snapping until at last the tongues meet in a flaming arc which rises in a mighty turmoil of electric flame twenty feet high. What was mere hissing becomes a roar as the arc strikes and restrikes across the empty space within the triangle. In a photograph the arc looks like a delicate web of minute threads of electricity.

Coronas are beautiful but useless. They represent leaks and constitute visual evidence that billions and billions of electrons are streaming out of conductors every second. The laws of corona discharge are now so well known that they are applied in preventing losses on high-voltage transmission lines. If engineers ever succeed in sending electricity at 1,000,000 volts, the wires will have to be very smooth and six inches in diameter. Corona studies have their bearing on the problem of lighting; for coronas, at least in the laboratory, are a form of tamed lightning.

What is the result of all this study in the laboratory and in the open? What measures are adopted to protect central stations? Billions of horse-power that flash through the air in a few millionths of a second cannot be tamed. They must be given a chance to wear them-

selves out, or they must be sidetracked. By means of automatic oil-circuit breakers and complicated insulators so much has been done to protect lines that interruptions of service are rare. But out of research has come a much more effective method—the sidetracking method. Extra 'shield' wires are strung from one transmission tower to another, just above the conductors, and then a connection is made with the earth. Hence the term 'ground wires'. Still other ground wires run from the steel legs of the towers to terminals sunk in the earth many feet away. A 100,000,000-volt lightning-bolt refers these ground wires to the transmission line, and by them it is diverted into the ground; where it spreads out harmlessly. A 66,000-volt line in Pennsylvania has been thus safeguarded for twenty-one years.

But is not this a modification of Ben Franklin's familiar lightning-rod? It is. And we have made no progress since 1752? We have. Great progress, in fact. Franklin's principle, the result of correct reasoning rather than of any experiment he may have made with kites in a thunderstorm, is the only one that can be applied. But protecting a line hanging from the insulated cross-arms of steel towers and extending in some cases 250 miles across open country is a very different matter from protecting a house or a barn with a properly grounded rod or two. Only after painstaking measurements of real lightning, only after experimenting with artificial lightning on models and on full-sized transmission systems, could the forces that

had to be sidetracked be gauged. Engineering adequacy was essential, and that could be assured only by research. Modern lightning protection for central stations is measured protection.

XV. Speed

THE WHOLE HISTORY OF SPEED IS A HISTORY OF RIDING. A horse is a living engine. An automobile is a mechanical eagle. Men ride both. Is it strange that the first efforts to create artificial animals should have been rather crude imitations of nature?

A bird flaps its wings. Hence centuries were wasted in the attempt to make a mechanical bird with wings that a man might move with levers. Wings were strapped to arms and inventive fanatics even leaped from cliffs in fatal attempts to flap through space. A technique of invention had to be evolved before mechanical creatures could be devised which would whisk a man through the air as if on a magic carpet. Even invention was not enough. Science had to study what Solomon called 'the way of an eagle in the air' and the invisible swirls, cascades, and billows in the air itself before the airplane could be invented. Who was the primitive savage, conscious of his own limitations, who first dared to ride a wild horse and thus increase his own speed? How did he learn to tame horses? Whoever he may have been, he was a modernist in his thirst for speed, a scientist in his longing to use his brain and let another organism work for him, the precursor of engineers who now design airplanes that cleave the air at 400 miles an hour, the ancestor of unborn technicians who will ride not mechanical wings but rockets to the moon.

Is there any limit to speed? In the dense lower atmosphere there is. Tests were made in the huge windtunnel of Langley Field, Virginia—a structure in

which a storm can be created that dwarfs anything experienced on earth. An airplane was suspended within the tunnel while a gale rushed from one end to the other at 800 miles an hour. The forces to which the machine was subjected were measured. In other words, the process was the reverse of flying. It was found that at about 600 miles an hour the resistance in actual flight would be such that engines could not make much headway against it. The plane pushes a mass of air instead of parting it smoothly, just as a sled pushes snow. For practical aviation 600 miles an hour is the limit that laboratory science places on speed in the lower air.

Much is also made of the fact that the human organism has adapted itself to the earth—a planet of definite mass that pulls everything to it with a definite force. At rest, we are all subject to what the physicists call an 'acceleration of g', the 'g' being gravity. There is some reason to believe that for about two seconds 8g can be endured, but that 10g may result in injury if not death. But the evidence on which these deductions are based is none too good. Men have fallen from high bridges into rivers at more than 8g and have been none the worse for their experience.

At the beginning of the century there were scientists enough to predict that the human body could never withstand more than 100 miles an hour. Before the war the limit was raised to 200. Biological processes are certainly affected with an abnormal increase in speed.

On a straight course the hazards are not great. But the turns! If they are sharp the heart beats faster and often the blood rushes to the nose. And then the 'blackout'—the removal of blood from the eye by centrifugal force. Yet consciousness and control of the muscles are retained. Experts hesitate to predict what would happen on a turn made at 300 miles an hour. Yet R. L. Archerly of the Royal Air Force once looped the loop at that speed and topped off the performance with a perfect barrel roll. It is quite possible that racing pilots sometimes make turns at speeds so high that the centrifugal force presses the brain stem almost to the point of death.

But these are exceptional circumstances. The atmosphere is vast. There is no reason why the pilot of a commercial airplane should subject himself and his passengers to the agonies of sharp turns at high speed. Nor is there any physiological reason to fear straightaway travel at 600 miles in the lower atmosphere—the troposphere in which we live—or a possible 1000 miles an hour or more in the stratosphere at levels where air resistance is but a fraction of that known to us.

Always it has been energy that made speed possible. A running man, a galloping horse expends energy in travelling fast, and the higher the speed the greater the expenditure of energy. So it was natural that the first mechanical vehicles should have been designed with no other thought than that of carrying engines without shaking themselves to pieces. And the vehicles

themselves were adaptations of natural or traditional forms. The locomotive is still called the 'iron horse', not without reason. Such is the weight of tradition that railway passenger-cars are still reminiscent of the stage coaches from which they sprang. Automobiles do not wholly conceal their horse-carriage ancestry even in these days of rounded forms.

As we look back now at the evolution of our fast vehicles it seems strange that in copying nature we overlooked one essential of speed. The rounded breast of the vulture and albatross and stormy petrel, the rounded nose and tapering body of a pike—hunters and fishermen learned nothing from them for centuries. So we see the inventors and engineers, when at last they had unlimited power at their disposal, relying at first wholly on energy to attain speed. Bigger and bigger grew the engines, but the speed did not increase proportionately. Weight was saved, where possible. That helped, because it obviously takes more energy to haul a heavy weight than a light one. Ships were made slim of waist and sharp of prow on the principle that a knife cuts better if its edge is keen.

Yet a few physicists, all this time, were measuring energies and speeds—trying to find out why it was that it took so much energy to increase speed by only a little. There was William Froude, for example, brother of the famous historian James Anthony. That painstaking scientist had H.M.S. *Greyhound* towed by H.M.S. *Active* while he made exact measurements. He built a towing-tank and made more measurements

with models of ships. It might be supposed that as the speed is doubled the resistance is also doubled. Actually it is quadrupled. It goes up as the square of the speed. Worse still, the power increases as the cube, so that if it takes 2000 horsepower to make 10 knots it takes 8000 to make 20.

All this applies to railway trains as well as to ships. The physicists were exclaiming: 'Cut down resistance. Bluff fronts and sharp prows are equally wrong. Get rid of all projections.' No one paid any attention. Funnels that belched black smoke, waves that curled up under bows, foaming wakes—these were the evidences of speed. They were also evidences of blind inefficiency.

It was the aeronautic engineers who made the word 'streamlining' part of the everyday vocabulary. They were less hampered by tradition than the builders of locomotives and ships. From the very first, men like Lilienthal in Germany, Maxim in England, Langley and the Wrights in America, had measured resistance. They knew what it meant in energy wasted to rake the air with a hundred wires and stays. Eiffel and Prandtl experimented with wind-tunnels. Forms by the hundred were studied to discover which one could be pushed along with the least disturbance to the air. Everything was tested — wings, propeller-blades, struts. It was better, they found, to drive a correctly designed bulk through the air than to rake it with excrescences.

Out of these researches came a hull, rounded like

an egg in front, tapering off in the rear. Wings, too, were bluntly curved in front and tapering. Even struts were given the new shape.

It was incredible how speed records in the air were broken when these principles were at last adopted. In 1913, fifty miles an hour was about all that could be expected of an ordinary plane. In 1931 Stainforth of the Royal Air Force won the Schneider Trophy by attaining a speed of 407·5 miles an hour—since beaten by more than thirty-four miles an hour.

Had any of the recent record-breakers been exposed to the air, his frontal area of some four square feet, seated, would have encountered a resistance of about 2000 pounds. And had he put out his hand, his wrist would probably have been broken. At the terrific speed of more than 440 miles an hour the air-pressure upon it would have amounted to about ninety pounds to the square inch. As it is, the pilot slips through the air with no sense of the pressure upon his machine. He is merely the brain of a mighty mechanical sea-bird.

Streamlining alone does not explain the new speeds. It can do no more than to reduce resistance and make better use of the energy available. Engines, powerful engines, will always be necessary.

The more perfect the vehicle, the more perfect must be the surface. Ordinarily we give little thought to the railway track and the concrete highway and the part that they play in high-speed travel, yet without them our locomotives and our record-breaking automobiles would be useless.

Why do the automobile record-breakers journey all the way to Florida or Utah to test their cars? Because there they find the only stretches long enough and smooth enough in a civilized country. The ideal track for breaking the mile record would be fifteen miles long, level as a billiard-table, and straight.

What appears to be a fine smooth beach at seventy or eighty miles an hour becomes rougher than a corduroy road at 200 and therefore dangerous. The high-speed machines seem to flutter over the beach because of the wind ripples on the sands. The slightest unevenness causes wheel-spin and a drop in speed. A bump two or three inches high makes the car leap twenty or thirty feet forward clear of the ground.

Let the optimist who believes that if a record-breaker can make nearly five miles a minute a stock car of the future can do likewise on the open road, consider what must be faced. A record-breaker is built to race for just a minute and a half. It carries about 30 gallons of water and 28 of fuel—only enough for ten miles or two runs in opposite directions over the course, including the stretches required for acquiring speed and slowing down. It cannot possibly run fifteen consecutive minutes at 250 miles an hour without breaking down. Nothing about it is normal. Brakes have to be applied by a motor because muscles cannot perform the task evenly enough. A little hole is bored in the windshield to let in air. Otherwise goggles would be sucked off the forehead and perhaps the driver himself

out of his seat. At 245 miles an hour the wheels make about 2300 revolutions a minute. Even the tyres, specially made to withstand a run of 350 miles an hour, are good for no more than four minutes. The treads are only one thirty-second of an inch thick. If they were heavier they would be flung off by centrifugal force like mud.

The marking flags are usually set 100 yards apart. As the car races faster and faster against time they draw together. At 200 miles they are like the pickets in a fence. Only twelve seconds elapse before the run is over.

A tail has to keep the machine on its course. If the car slews around only slightly at full speed the tremendous pressure of the wind straightens out the fin again. A side wind tends to deflect the car from its course. Hence the watchful eye kept on the wind and the wind-gauges. Lead is used to weigh the car down and enable it to grip the sand.

We see, then, what 250 miles an hour or more on the open road means. Highways perhaps 500 feet wide and as straight as surveyors can make them for stretches of 100 miles or more; cars provided with stabilization fins and devices to prevent them from becoming airplanes; tyres of sturdier construction than those made for racing, since they must run for hours and not for minutes; and engines of a power undreamed of for cars produced in the quantities to which we are now accustomed—pile up the conditions, and the prospects become more and more

dubious of speeding at more than 100 miles an hour on the open road.

Automobiles being limited by rather narrow curving highways at present to an average of less than 100 miles an hour, it is to steel rails that we must look for greater speeds on land. Driven by the competition of the gasolene engine and the concrete road to recapture their lost passengers, the railways have at last listened to the physicist.

Articulated trains, driven by oil-electric motors over straight stretches at 110 miles an hour, usher in the new streamlined era. Not even a whistle protrudes from one of these metal serpents. Everything is tucked away in neat recesses.

But is this the end? Long before streamlining had been applied to airplanes, engineers and inventors had developed on paper ingenious monorailways on which average speeds of 150 miles an hour and maximum speeds of 200 and more were possible. Trains which could run on single wheels in tandem and cross an abyss on a steel cable and which were held up by gyrostats when they came to a stop—one sighs to think they never had a chance because of the heavy investment in a system that is but the offspring of wooden stringers laid in the mud of a mine and over which horse-drawn coal-skips could crawl without sinking to the hub.

We have now reviewed what has been accomplished in attaining high speed with the aid of mechanical energy and correct modelling to reduce resistance.

We have seen that only a racing car can exceed 300 miles an hour and that stock automobiles are not likely to exceed 100 miles an hour, because there are not enough long, straight stretches and because an entirely new and much too expensive type of vehicle would have to be designed for anything approaching 200 miles an hour.

So it is up into the stratosphere that we must climb if we are ever to attain commercial speeds of 600 miles and more. For in the blue there are no narrow concrete roads to consider, no tracks with sharp curves. In that uncanny layer there are no clouds, no storms, nothing that we designate by the word 'weather'.

More important to the aerial navigator is the almost total absence of wind. With the air only one-ninth as dense at 50,000 feet as at sea-level an airplane can travel faster than sound.

There can be no doubt that the stratosphere will at last be conquered. But an airplane must be evolved which differs as radically from that in which we soar from New York to Chicago in five hours as the streamlined train of today from the steam train with its lumbering coaches.

Climbing to 50,000 feet—that is in itself a formidable technical difficulty. In the stratosphere it is harder for blades to bite the medium, harder for the propeller to screw itself forward. But the first successful variable-pitch propellers have already been made.

Then there is the matter of the engines. They breathe air just as a human being does The altitude

of somewhat more than seven miles possible with special airplanes of today can be attained only with superchargers—devices that pump air to the gasping engine. Something better is needed for stratosphere flying. Possibly oxygen.

If engines gasp, what of crew and passengers? They must take their places in a hermetically sealed fuselage, properly warmed. An artificial atmosphere must be created with the aid of liquid oxygen slowly released from steel bottles or of superchargers. The vitiated air must be cleansed with chemicals or expelled. Moreover, the artificial atmosphere will have a pressure higher than that of the surrounding stratosphere, which means a stout construction to prevent the fuselage from blowing apart.

Remembering that in an airplane ounces must be saved, problems are presented by these and other considerations that have thus far proved too much for the best aeronautic engineers of our time. Yet who can doubt that the stratosphere airplane is the next step in the attainment of speed? Breakfast in New York, luncheon in London—the feat will be a commonplace fifty years hence.

XVI. A Liner Leaves Port

THERE IS NOT MUCH DIFFERENCE BETWEEN THE POWER-plant of a great liner such as the *Queen Mary* or the *Queen Elizabeth* and the central station that supplies a city such as Boston or Detroit with electricity, except that the liner not only generates energy but applies it to drive propellers, light lamps, cook food, run lifts, make electric horses in the gymnasium jounce up and down. It is the compactness of these hundreds of pumps, motors, switchboards, these miles of asbestos-clad pipes that impresses. A watch is no more tightly packed with mechanism than is the hold with machines of a hundred different kinds.

The boilers are strung along the bottom in compartments, each as large as a ballroom. It is about as hard to enter one of these rooms as it is a bank vault. You pass through an airlock—a space between two hermetically sealed doors. Open the outer door and step into the space. At once the inner door is locked. It cannot be opened until the outer door clangs behind you. If for some good reason the inner door is open—an officer coming out of a boiler-room, perhaps—the outer door is locked. Signal-lights visible through windows tell whether the way is clear or not.

Why all this mystery and ceremony? The ship has what is technically called the 'closed stokehold system'. In plain English this means that the fans by which the oil fires are kept at white heat blow not directly into the furnaces but into the boiler-rooms. So the air in the boiler-room is above atmospheric pressure—not much, but enough to set up a rush

through the fireboxes and funnels.

Forced draught depends on superatmospheric pressure in every one of the boiler-rooms. If there were no airlocks, if a boiler-room were to be entered or left with no precaution, the engineer in charge would know it quickly enough. A twitching indicator would show that the pressure was jumping up and down.

The boilers are more sensitive to 'feed water' than the human stomach. There are objectionable mineral salts held in solution. Sooner or later they would crystallize inside the boiler-tubes through which the water courses. And sooner or later nearly 150,000 tubes would be clogged. Every day 300 tons of fresh water are sucked out of the double bottom by centrifugal pumps, filtered, stirred up with a creamy solution of lime and soda, agitated by blasts of air, precipitated and otherwise reduced to a proper state of chemical impotency. To keep the water pure in an engineering sense, tell-tale instruments are periodically read. They indicate the chlorine and alkaline content.

If by any chance you could introduce a pinch or two of salt into a feed-line, gongs would go off, lights would flare up ominously, fingers on indicators would point accusingly to danger-marks, and an engineer would at once make an investigation. In fact, one way of testing the instruments is to pour a glass of first-class table water into the feed-water line. If the result is the expected instrumental anguish, all is well with the alarm system. There is also a little chemical

laboratory where one of the engineers makes a few simple tests every day just to be sure that the water gulped into the boilers is of the required softness.

What goes into the boilers is no more important than what comes out of the funnels. Hence the flue-gas indicators. If there is too little carbon dioxide (which does not burn at all) and too much carbon monoxide (which does burn), the fires are not what they should be.

Thick masses of smoke curling out of funnels are not an engineer's conception of perfect combustion. The less smoke the better. Automatically every engineer on the ship glances up at a mirror when he passes certain places. It reflects down into the stoke-hold the beam from an electric lamp. The beam has to travel across the funnel. If there is no reflection there is too much smoke.

Nowadays large passenger liners are fired by oil. Gone are half-naked coal-passers and stokers, gone the scraping and clanging of shovels, gone all the grime and much of the sweat. How much oil a record-breaking liner burns in a day is a dark secret. But since there are fast steamers that burn no more than six-tenths of a pound of oil for each horse-power in an hour it is a fair guess that 1100 tons of fuel oil a day will suffice when the *Queen Mary* or the *Queen Elizabeth* is doing her best.

Boiler and engine efficiencies have improved in the last twenty years. There is more superheating of steam than there used to be. Steam-pressures are higher.

Heat is saved as if it were tangible money. Before gases stream out of the funnels they preheat the air and the oil that reach the burners.

With dazzling flames roaring from 168 burners it might be supposed that the boiler-rooms would be barely tolerable. It is just warm summer weather in the stokehold year in and year out. You can rest your hand on a boiler, so effectively does its overcoat of thick asbestos keep in the heat.

When the order comes down from the bridge for a burst of speed or the engineer in charge of the boilers sees that more steam will be needed, there is no excitement. He simply turns on more oil—turns it on himself or tells some junior officer to do it. Thereupon, nozzles out of which filtered oil sprays in fine jets burn with a little more intensity. But when the ship is to be driven hard he may order burner-tubes removed and others of larger size substituted. It takes only a few minutes. Changing tyres on an automobile is harder, more time-consuming. There is none of the fussing, none of the swearing, none of the fuming that we associate with Mississippi steamboat races of Mark Twain's time.

Aft of the aftermost boilers are the spacious engine-rooms—two of them, spotlessly clean, separated by a bulkhead. Disappointment awaits you if you are thinking in motion-picture terms of old-fashioned engines. Here is a ship that has made over thirty-two knots—that may be actually making thirty as you stand amid her propelling machinery. And yet noth-

ing apparently moves. The engine-room of a ferry-boat is far more active. There are no rods flashing in and out of tall cylinders, no thumping pistons. This little world is turbine-driven, and a turbine is simply a huge, horizontal, unromantic, drumlike box of steel in which turns a spindle carrying thousands of vanes. Shoot steam against the vanes just as wind is blown against a windmill and the spindle rotates. All that you see is the outer casing and that tells you no more of the whirling within than an unlabelled tin tells that it contains tomatoes.

Not until you reach the after end of the last turbine do you see anything that turns. There your eye falls on one of the four propeller-shafts. They are hollow and as big as many city water-mains. Watch them closely; their glint tells you that they are whirling. Far at the outer ends furious 35-ton four-bladed bronze propellers thrash the sea into a frothy wake.

Steam flashes through a turbine with the speed of a rifle-bullet. After it has pushed and kicked the vanes of the high-pressure turbine around there is still so much energy in it that it can drive a first intermediate-pressure turbine, then a second intermediate and a low-pressure turbine. Finally it goes into a condenser—a gigantic box filled with thousands of tubes through which cold sea water constantly flows. By that time it is weary and tepid. What little life is still left in the form of heat the condenser absorbs. Chilled by the cold tubes, it falls in a rain. There is virtually no air in the vacuous condenser—nothing but the

rain, which goes back again into the boiler feed-line. Fresh water is too precious to waste.

Turbines are high-speed machines. The *Queen Mary's* or the *Queen Elizabeth's* sixteen (four to a shaft) spin at 3600 revolutions a minute. On the other hand, a propeller does its best work at 240. When turbines were the newest mechanical marvels, back in the nineties, their spindles were extended astern to become propeller-shafts. With this arrangement the screws did not grip well. The water had no time to flow in. What the engineers called 'cavitation' occurred. Hence the modern practice of driving propeller-shafts through gearing.

The four sets of turbines have at the end of their common spindles helical pinions. The pinions mesh with gear-wheels fourteen times as big. The big gears, of course, are on the inner ends of the propeller-shafts. So by these meshing pinions and gears, housed in boxes, the 3600 revolutions of the turbines become 240 at the propellers.

The engine-rooms are not silent. Fast machines hum. Gears drone. Yet because of the steadiness and the insistence you are scarcely aware of the assault on the ears. The engine-room is tensely vibrant. Try to talk. The voice must be pushed out of the throat against the tension.

The liner draws on her maximum horse-power of 200,000 only when she is driving at well over thirty knots. When she picks her way through the crowded shipping of New York Harbour and the Hudson

River, and manœuvres in and out of her berth, she needs only a fraction of all that power. Her turbines are therefore divided into two propulsion-plants. Cut out either one and she becomes a twin-screw ship for the time being.

But this means in turn two engine-room staffs directed from the bridge. It also means two control-platforms, which are of cerebral importance and which run right athwart the ship. They are like high bridges that overlook the entire engine-room. Lean over the slightly oily steel railing and you see below the non-committal turbines and a score of auxiliary machines, pumps, electric motors, and huge steam-pipes lapped in asbestos.

The engineers on the platform glance occasionally at about a hundred instruments arranged on what is called the 'dashboard'. Gauges indicate the pressure of the steam that flings itself at the vanes in a turbine, tachometers count the revolutions made by the turbines and the propeller-shafts, inclinometers show the tilt of the ship. Then there are oil-pressure measurers, vacuum-gauges, voltmeters, ammeters, and thermometers to tell how hot the steam is.

All these instruments are in effect mechanical senses through which the ship's many machines communicate with the engineers on the two platforms. 'Feeling fine, making 3200 revolutions a minute,' reports a turbine spindle through a tachometer. 'Oil-pressure beginning to fall,' warns another. 'Vacuum's not high enough,' says a third. The instruments are fairly

steady, once the ship is under way. Some indicators hardly move for hours.

Because there are limits to what the human brain can grasp, the engineers do not rely entirely on the instruments. Long before danger-points are reached in any important part of the propelling machinery, red lights flare up, gongs ring, whistles blow, klaxons scream. In addition there are many devices that prevent the making of a false move in turning a valve or throwing a lever—precautions that again take the form of suddenly glowing lights or clamouring gongs.

The bridge and the platforms can talk to each other through telephones as well as to other parts of the ship. But most of the communication takes place through engine-telegraphs. The bridge has one set, each platform another—duplicates. For each of the four sets of turbines that drives a propeller there is a telegraph.

In the middle of a telegraph-dial is a peremptory 'Stop', and on either side of that are orders reading 'Full', 'Half', 'Slow', 'Dead Slow', and 'Stand by'. When the bridge signals 'Slow', gongs ring and the indicator on the corresponding telegraph on the platform obediently moves to 'Slow' on the left or 'Ahead' side. The proper engineer on the platform moves a lever to 'Slow', and an answering signal in bells signifies to the bridge that the order has been received. Manœuvring is so completely in the hands of the executive officer on the bridge that he telegraphs what particular sets of turbines are to do.

Starting the machinery is easy enough. It is done by means of horizontal wheels about three feet in diameter. The long spindles of the wheels extend to the steam valves. A turn of a wheel and steam shoots from a high-pressure nozzle into the high-pressure turbines.

Every minute of engine-room time is accounted for in a record kept by one of the engineers on the platform. When, for example, the *Queen Mary* leaves New York on a weekday morning, the movement log may look like this:

Starboard		*Port*	
Astern slow	11·01	Astern half	11·01
Astern full	11·12½	Astern full	11·12½
		Stop	11·15
		Ahead half	11·16
		Ahead full	11·18
Stop	11·21		
Astern half	11·23½		
Astern full	11·24½		
Stop	11·26		
Ahead slow	11·26½	Ahead slow	11·24½

All this means that the liner with the assistance of busy tugs is backing out into the Hudson, that propellers are now churning ahead and now astern to head her downstream, that at last she is steaming slowly down the river into the bay. An hour and a half later the pilot shakes hands with the executive

officer on the bridge, scuttles down several decks, clambers down a ladder over the side into a bobbing rowboat which takes him to the pilot boat. Then the engine telegraphs of both platforms ring 'Stand by'. A minute later comes the signal 'Half' and then 'Full'.

The ship is on her way.

XVII. *Electric Immortality*

ALL ABOUT US ARE GHOSTS. THEY SLIP INVISIBLY THROUGH the ether with the speed of light. They glide over wires in less than a second from New York to San Francisco. They come and go on television screens. Not ghosts of the dead are they but of countless living men and women who sit in their homes and their offices and send their discarnate personalities to the uttermost parts of the earth and charge them to deliver messages of love and hate, joy and sorrow, to gather news of life and death, success and failure, and bring it back in the twinkling of an eye. Nothing in the dubious annals of spiritualism even remotely approaches the miracle that science performs in disembodying the living.

I pick up the telephone and ask for a connection with Clarence Brayton, 23 Stockton Street, London. Fifteen minutes later my bell rings and the operator informs me that London is ready. Brayton and I talk. So far as the conversation goes we are sightless, even bodiless. The engineers have reduced us to two voices and two pairs of ears, and sent their electrical equivalents shuttling back and forth across the Atlantic. 'Stripped of flesh' is the *Oxford Dictionary's* definition of 'discarnate'. If ever living man is stripped of flesh yet permitted to communicate, it is when he telephones. A sense is given the power of leaving the body and travelling through space; yet the body, unaware of the process, is left intact.

With radio broadcasting the discarnation assumes an even more bewildering aspect. The President sits

in the White House, half a dozen microphones on his desk, and speaks of the state of the nation. Through mountains and walls his electric ghost passes, as light through glass. He ripples through space and enters millions of homes. Half the planet hears. The transmitting apparatus by which he is disembodied is a small dark sun that radiates him invisibly. And the receiving sets in our homes are merely electrical and mechanical eyes that see him and translate him to us in terms of the spoken word. We create an electrical organism to perceive an aspect of him to which our physical eyes are blind. He is all voice to us; we are all ears to him.

Now that we have television we carry the process still farther. Quite painlessly a face is minced into 250,000 bits of light and shade every second. 'Take this bit of left eye and put it exactly where it belongs on the screen,' orders the transmitter. And the receiver obediently puts the bit of left eye where it belongs in Chicago, St. Louis, in scores of places at once. So with every part of the face. It is a mosaic—that television image on the receiving-screen. But a mosaic which is pulled apart and pieced together so rapidly over and over again that the eye cannot follow the process and accepts the vision as a whole, just as it accepts as a whole a man crossing the street.

Some day we shall have stereoscopic television—images in full colour with an apparent third dimension. Though we may be enthralled by a drama on a motion-picture screen, we know that the photographic

players are only flat recognizable masses of light and shade. With television of the future it will be different. Figures and faces will appear life-sized; they will have solidity. In fact they will seem as real as if they were actually in the room. But walk up to them and feel them. Try to take from a spectral hand the flower that it offers. Only the surface of the screen will meet the touch to prove that these men and women who smile and gesture are but ghosts after all.

There are tales enough of clairvoyance—of persons who have seen, darkly as in a glass, events that are happening in the uttermost parts of the earth. But in television we have the clairvoyance of science, the kind that can be controlled with electrical circuits and switches. Crystal-gazing assumes a new dignity when the glass is a television-screen.

Think now of the social consequences a generation or so hence. The world is struggling in the throes of war. Desperately the Prime Ministers of the European countries involved, the President of the United States, and the heads of the principal members of the British Commonwealth of nations (once colonies) are trying to find the way that leads to peace. They do not journey physically hundreds of miles to one spot as Chamberlain, Hitler, Daladier and Mussolini did in 1938. They meet electrically. A convention of spectres settles the fate of civilization.

The President of the United States sits in a television-room next to his office. Around him are a dozen

screens as large as those in motion-picture theatres of our own day. He is in the dark, yet in a blaze of invisible infra-red rays. A camera points at him incessantly. Pitilessly it catches every passing frown, every hopeful glint of his eye. And so with his communicants in distant cities. He sees their electrical ghosts on the screens around him; he hears their discarnate voices.

'I deny categorically that paragraph forty-five, section two, of the Treaty of Madrid either says or implies that we are not to use atomic energy for the production of synthetic gold,' says the Japanese Prime Minister too vehemently. 'I hold up the document and I point to the paragraph and section in question. Read for yourselves.' He shakes his free, clenched fist at the phantoms around him. On twelve screens in twelve widely separated capitals the Japanese glares indignantly through his horn-rimmed spectacles, and a close-up of the treaty appears, so that all may read. His clenched fist has been transported with the document.

'It is true that the section says nothing about synthetic gold specifically,' observes the ghost of the British Prime Minister as it appears simultaneously in the twelve rooms. 'But I submit that the sentence, "Atomic energy shall not be used to undermine the economic, financial, and monetary structure of any signatory nation," has but one meaning.' There are times when the twelve ghosts are all talking and gesticulating at once, so that the President of the

United States, the chairman, has to rap for order and beg them to restrain themselves and permit him to conduct the conference in a seemly fashion.

A sceptic will object that international conferences at which the fate of the world is settled are usually secret and that radio in any form is as public as the blue sky. The engineer replies that long before 1929 transatlantic conversations were scrambled in transmission and unscrambled at the receiving end by special mechanism, so that even if, by some miracle of good luck, an eavesdropper in space stumbled upon the wave-length on which they were conducted, he heard only gibberish. So with these conferences of important phantoms in the future. Suppose they were plucked out of the ether. On the screen only a shapeless, chaotic, ever-changing smear of light and shade would appear; from the loud-speaker only unintelligible hisses and gutturals would well.

But the real point of this controlled electric clairvoyance, this meeting of images, minds, and voices at selected points on earth, is the separation of sight from the human body. Even in our backward technical day two senses, sight and hearing, are stripped of flesh. Is this the end?

Before modern inventors entered upon the scene only poets, Hindu mystics, and spinners of fairy-tales dared to dream of personalities that left bodies and transported themselves all over the world. It seemed wildly improbable so late as 1870 that one man could ever talk to another over a distance greater than a

human shout could bridge. And even after the telephone was introduced and the way for seeming electrical miracles prepared, it was incredible that the image of a face would be dismembered and pieced together again thousands of miles away. The romances of yesterday are the realities of today. So, just because my great-grandfather and yours, if they had read about their speculative possibility, would have regarded the telephone and television as poetic moonshine, I believe in teletaction—electrical feeling at a distance—as a reality of the future.

How it will be possible for me to shake hands electrically with a friend in San Francisco or Paris, or how I shall pass a remote electrical hand over my beloved's hair while she is in the middle of the Indian Ocean and I am in New York, I do not know. If I am hard put to it I can imagine myself thrusting my hand into a box, with little metal feelers almost caressing it as the skin's electrical halo is explored. I can imagine corresponding electrical impulses travelling out into space, just as impulses now travel out when I talk into a radio microphone. And I can imagine these impulses from my warm, slightly moist skin reaching an apparatus in which there is an appliance that serves to create an electric field or halo exactly like that at the sending end. My friend at the receiver brings his hand very near that appliance but does not actually touch it. Little electric waves run from it. A halo is produced—the counterfeit of my hand's. Just as a diaphragm in a telephone-receiver duplicates the sound of my

voice, so these waves will cause a response that he will accept as the touch of a real hand. The effect of little wrinkles, the warmth, the slight moisture—everything will be felt.

The transmission of smell and taste, though just as fantastic now, may be even easier than teletaction. The two are intimately related, which makes me think that the electric palate will have to be combined with an electrical nose if I am to taste and sniff in New York a dinner served in New Orleans. There will be no nourishment in these Barmecidal electrical feasts. I might starve to death as I smelled and tasted the creations of a remote Escoffier; but I could indulge in the most extravagant gluttony without ruining my digestion or experiencing the slightest discomfort. And the wines of notable vintage that I could guzzle by the gallon without slipping under the table in a sodden stupor!

When we now watch a film drama unfold on the screen we obligingly attribute the voices to the photographic players, forgetting for the moment that pictures cannot speak. Are our imaginations so powerful that they will similarly combine five different sense-impressions at once and create an overpowering illusion of reality? Perhaps. Before the talking motion-picture was introduced, sceptics doubted the possibility of fooling eyes and ears simultaneously. The necessity of instantly accepting five separately received sense-impressions makes me think that we shall not have time enough to be analytical. Besides, we shall be in

the gullible frame of mind that now makes us forget that actors on the motion-picture screen are not living human beings.

How evanescent are these electrical extensions of the senses! When I hang up the telephone-receiver the world returns to what it was. A snap of a switch to break a circuit and the radio ghost is laid, whether he enters the room by way of loud-speaker or television-screen. Yet it need not be so. These ghosts can be way-laid, trapped, and brought out to strut, play, sing again. For every vibration can be recorded and reproduced.

It is a common practice nowadays to transcribe radio addresses. The moving valedictory of former King Edward when he announced his abdication was sold on disks in New York twenty-four hours after it was delivered. So with television. The shifting image can be recorded as a sound-track on a phonograph, for the electric waves that carry the bits of image can be made to vibrate a recording needle. Images are now translated into grunts, squeals, gasps. To the untutored ear they are meaningless—these queer noises. But the practised television engineer can say: 'Sounds like Bergner's face. And that second record, I'm almost sure, was a park or meadow. Green grass buzzes like that.'

You do not have to listen to sound records for months, like such an engineer, before you learn to distinguish one face from another by ear. The noises can be changed back into electric waves and the electric

waves again into visions that make sense. And so will it be with teletaction, telegustation, teleolfaction, if we must coin words to correspond with 'telephone'. Whatever the sense-impression may be, it can be recorded as sound. And the sound can be produced, converted into waves that will slip through the ether or over a wire, and the waves translated at their destination into things that we readily mistake for the originals that were felt, tasted, or smelled.

With five sense-impressions to be recorded and reproduced at will, that dinner which I relished so much with Rosalie, back in 1982, at the Villa Farnese is not wholly of historic interest. I can enjoy it again and yet again. Our flirtatious quips, her derisive laughter, the music of the little orchestra bursting in, the vision of us, as we sat in the open under the trees, everything will be preserved for my ageing enjoyment. Even the dark suggestion of Lake Como in the distance and the occasional dropping of a leaf upon the table.

You see now what I am driving at. Immortality! Electric immortality! Those old tales of the dead that come to life again in the graveyard for a few brief hours, they seem more credible now. For all the electrical ghosts of the dead past can be called out of their sound-track tombs not by mumbling cryptic formulas and other medieval hocus-pocus, but by electron-tubes, induction coils, switches, and control-knobs much like those of any radio-set of today. There is only one condition. The past must have been decently entombed

as sound with benefit of science. Let it escape into space and it is lost for ever.

To be sure, the ghosts will make the same gestures, repeat the same words. Their hands will always press ours with the same pressure. And the aroma of the roses of the past that we shall drink in will never change. Yet how much more real will these electrical phantoms be than the lifeless words of my diary: 'December 31, 1938. New Year's Eve at the Flamingo Club with the Underwoods. Everybody very gay and rowdy. Didn't leave until 5 a.m.' It is a pleasant pastime to clothe such an entry with meaning. But it requires a creative effort of the imagination. And however gratifying the result, it is a departure from reality.

What do we know of the circumstances that attended the signing of the Treaty of Versailles? The correspondents described the public meetings of plenipotentiaries in the most vivid words that they could muster. There are men alive who were actors in that drama. Yet what are their words compared with the event itself? Even the art of Shakespeare is inadequate to describe what occurred. We want to be at the scene—see, hear, touch Wilson, Clemenceau, Lloyd George, and Orlando. We want to experience the event, participate in it. The actual life of the past—this is what we want. And science has already laid the foundations of what may be called 'survival engineering' with the telephone, radio, television, and the art of recording electrical and mechanical waves and vibrations.

It is more than probable that your slightly ribald great-great-grandchildren are destined to become acquainted with you through your trapped ghost. ‘ Let's get the old boy and find out what he was like,’ your descendant says. He climbs a step-ladder, takes from a shelf a package of sound-tracks (film or disk) to which you are now reduced, dusts you off, and ‘plays’ you, just as you play the latest dance record. And you live again, just as you lived at the moment when the fragrance of your boutonnière and the sight, sound, and touch of you were translated into electric waves. Your ghost walks, smiles, laughs, opens its arms for an embrace.

‘ Why did he have to choke himself with that cravat and collar? ’ someone asks.

‘ It's easy to see that our hormonic youth-preserver, androsterone 27, had not yet been isolated,’ another will comment. ‘ That grey hair at sixty, those wrinkles, that leathery skin—how shocking, how unnecessary, how easily avoided! ’

Magnify any sound-track and it appears as a wavy line with curious saw-teeth, rounded humps, and valleys. Physicists and engineers who devote their lives to studying the mechanisms of speaking and hearing can draw on paper almost from memory a fairly accurate curve which means nothing to us but which says ‘boat’ to their minds' ears as loudly as if the word were yelled. In fact, a German engineer has gone so far as to propose that motion-picture producers dispense with orchestras. ‘ Draw on paper the kind of

wavy sound-track that musicians make when they are playing "The Blue Danube", transfer this either to a phonograph disk or to a film, and you do away with trombones, violins, clarinets, and the bother of controlling a hundred men with artistic temperaments,' runs his formula. And no audience would be the wiser, if the draughtsman of waves has done his work well. How easy to correct a wrong note by redrawing an inch of the curve, or to soften an unpleasant blare of brass!

If this is possible now, as it is, then a century hence, probably sooner, we shall create sense-impressions of things that never existed. In wavy lines sound-track banquets will be drawn at which impossible dishes will be served, to become illusively real when 'played' on a phonograph or run off in a motion-picture projector. Heavens and hells, angels and devils, will outdo those of Dante and Milton because they will carry three-dimensional, sensory conviction with them. A new dramatic art will be born, which will demand the combined gifts of Shakespeare, Wagner, Michelangelo, and of experts in the synthesis on sound-tracks of perfumes and flavours, of tactile sensations that will be an abyss of horror or the pinnacle of bliss. The last vestiges of the stage will disappear. Drama will be played in the home by actors who were never more than figments of the imagination, never more than ghosts, who will sing verses and utter words that were never sung or spoken and who will walk and live and love in palaces and gardens that were never

even painted scenery. Synthetic ghosts who have their being in a synthetic world that never could be—even the Hindu mystics never thought of that.

XVIII. Democracy and the Machine

THERE WERE MACHINES IN GEORGE WASHINGTON'S TIME. Clocks, for example, and looms, and water-wheels, and in England some wheezy Newcomen steam pumps that kept mines dry. But George Washington, for all the part he played in encouraging American invention, never spoke of 'the machine' as he undoubtedly spoke of 'the church' or 'the law'. It remained for our time to sweep into one all-embracing symbolic generalization the countless mechanisms that light houses, drive trains, carry us across the ocean, convey speech across continents, make clothes, can food, build houses, dig canals, spread the voice of an abdicating king over the whole earth, gather and print the news of the world for presentation on the morrow's breakfast-table.

As soon as we begin to talk about 'the machine' in this way personages melt into a vague anonymous background of roaring furnaces, streamlined trains, canning-factories, gas-works, fast presses. We grew up with heroes of invention such as Morse, Bell, McCormick, Westinghouse, Edison, and Marconi, but there will be fewer for our children's children to admire. It is not that invention is in a decline but that its character has changed. It is no longer the business of ingenious whittlers and tinkers alone. The trained corporation scientist and engineer already reigns.

Whether it is the making of beer-bottles or bath-tubs, furniture or clothes, rolling and packing cigarettes, we behold human capabilities multiplied a thousandfold by fingers, hands, and arms of steel.

What is even more important, we behold a transference to the machine of dexterity and something that at times looks weirdly like intelligence, as when we see an adding-machine totalling a column of figures; or photoelectric cells opening and closing doors automatically, counting vehicles as they pass a given point, sorting perfect from imperfect articles on a belt, or gauging the thickness of paper as it forms on a Fourdrinier machine.

Walk through a modern steel-mill. An overhead crane with a single man in a cab picks up a twenty-ton casting and lowers it neatly on a flat car. A reverberatory furnace is tilted and a hundred tons of white-hot metal pour into a ladle, whereupon the ladle travels along and pours the steel into a line of moulds, one after the other. Not more than half a dozen men are engaged in the whole process. And the energy at their command! The pull of a lever, the turn of a wheel, the movement of a switch releases ten thousand, twenty thousand horse-power, whereupon huge masses begin to move, rolls begin to turn, rails to come out. Turn this way or that and look about for human hands. They are there of course. Yet the mill seems singularly empty. It is destined to be emptier still. Even during the depression the laboratories and development departments were recruiting designers of new machines and draughtsmen to make working drawings. The few machine-tenders know what is happening and wonder—wonder when more short-cuts will be taken, when, for example, the process

of rolling will be so far developed that there will be no more reheating from steel ingot to finished sheet, with the consequence that more men will find themselves out of work.

Watch the mechanism of the wireless telephone. It is like seeing a colossal, infallible brain at work—rods that slide up and down, links that move just so far, selectors that pick out just the right combinations of gears and wheels to complete just the right circuit to ring just the right bell in response to the twisting of a distant dial. The mechanism is beyond the grasp of a single designer. It needs a crew of specialists. The chief engineer sees the mechanical brain as a whole—sees in his mind's eye all those rods rising and falling and making the right connections. But he could not design every detail.

Or step into one of the great automobile factories. You see a hydraulic forging-press. It costs £30,000, perhaps more. Essentially it is a steel fist that descends upon a sheet of steel, squeezes it into a mould with one relentless push, and so forms the fender of a car. Thirty years ago fenders used to be tailored like trousers. An ingenious mechanic might conceive the principle of the press, so simple is it. But he could no more specify the particular kind of steel to be used to build it or the dimensions of the parts or the pressures to be hydraulically applied, without a vast amount of prohibitively costly empirical experimenting, than he could smash atoms.

Individuality is disappearing more and more. In

great plants the machine-tools are set by the engineers at the top. The man who guides a travelling crane or who controls the motors of a rolling-mill is no more capable of repairing the mechanism in his charge than he is of taking the *Queen Mary* safely across the ocean. He may be astoundingly skilful in his manipulation of levers and switches, but other minds dominate the mechanism—design it, improve it, keep it in repair.

All this has been more apparent since the beginning of the century than it was before. The average worker did not see it clearly, but he realized that he was in the presence of a force that could crush him. Hence the history of invention is a history of resistance to technological advance.

Sometimes it was the state that interfered, as it did when Queen Elizabeth and James I refused to grant a patent to the Reverend William Lee for his stocking-frame, or when the manufacture of Giambattista Carli's looms was forbidden because of the effect on Venetian stocking-knitters, or when various German principalities prohibited the use of the ribbon loom. Usually it was the worker who protested. Cottage spinners destroyed Hargreaves's jennies. Arkwright's mechanically driven carding, roving and spinning machines were the objects of systematic attack and the subjects of appeals to Parliament. In the Nottingham Luddite riots of 1811-1812 knitters destroyed machines that could cut large pieces of inferior material into gloves, socks, and sandals. Jacquard lamented the demolition of the looms that he had invented for

weaving brocaded silk. The uniform-factory of Thimmonier was destroyed in 1841 by workers who saw nothing but starvation for them in its sewing-machines. Threshing-machines were broken up in England by seasonally employed farm-hands. The same grisly fear of displacement hangs over the worker today. Sabotage is not unknown, but a few very strong unions can and do insist that new labour-saving devices are not to be introduced if workers are to be dismissed.

Paradoxical as it may seem, much invention has been inspired by the anti-machine policy of the unions themselves. It was they who insisted on the passage of immigration laws which made it more difficult to recruit cheap European labour for trench-digging or shovelling ore in steel-mills or doing the manual work of the mill and the mine. The result is that when an oil or gas line is to be laid hundreds of miles, a trench-digger now does most of the work—a colossus that buries tooth-like shovels into the ground and gnaws its way from one end of a state to the other. There were steam-shovels before the major restrictions on immigration were imposed, but not the titans now busy on the Mesabi Range, where iron is dug up at the surface like so much dirt. We had labour-saving machines when wages were far lower than they are now. The point is that when wages go up it becomes possible, even necessary from a business angle, to invent machines of a new type and of unprecedented productivity. When, therefore, a manufacturer pro-

tests against fresh demands for higher wages or shorter hours and vows that he must either close or move to non-union territory, or when a financier decides that he will not invest his money in an industry because of high labour costs and small profits, he assumes that production costs cannot be reduced, that inventors are unable to meet the exigencies of a new situation.

In the decade from 1920 to 1930, one of steadily rising wages, the nation's output increased 46 per cent. but the labour force only 16 per cent. It would be fallacious to attribute this remarkable decline in opportunities entirely to new and more complicated inventions; yet Mr. David Weintraub, a close student of technological trends, finds 'a meaning' in the percentage which it is the purpose of detailed studies now under way to define.

But more than the effect of invention on the worker is involved. The tireless machine is the despot of our age. 'Regimentation' is an overworked word, but we must invoke it. The machine stands for mass production. And mass production means regimentation on a vast scale—what the engineers more politely call standardization. It is the machine in the last analysis that makes us dress more or less alike, ride in automobiles that are more or less alike, see at night by lamps that are absolutely alike, live in houses that resemble one another and are even identical when they are built in rows for the occupancy of mill-hands, eat canned and packaged foods that are indistinguishable from one

another. Fifteen million people a day see precisely the same films. Donald Duck is as familiar to western ranchers as to Rumanian shopkeepers on New York's East Side. By radio an entire continent listens to some popular comedian who is 'sponsored' by an oil-refining company with gasolene to sell. Water comes from a common reservoir, gas from a common gasometer, electricity from a common central station. Living has become a collectivistic activity. For life in Lima, Ohio, in its technological aspects is much like life in Chicago, San Francisco, or New York. Collectivism is forced upon us whether we want it or not.

Mass consumption, mass recreation, mass distribution of energy, and the collectivistic utilization of identical things are impossible without control of mass production, without organization. The inventors have standardized behaviour, pleasures, tastes. There is less freedom than there was a century ago because of invention; there will be still less tomorrow. The patents speak eloquently enough on the point. In the first third of the twentieth century 1,330,000 were granted in this country, with more than that number expected in the second third. Few are supremely important, but their increasing number indicates that technological thinking is more than ever directed towards utilizing energy for the production of goods.

Control. Organization. Without them mass production is impossible.

Who are the controllers, the organizers? A few experts at the top of the pyramid—efficiency engineers

who see to it that even the hugest steel-mill operates as if it were a single organism with a super-machine-tender in charge called the 'superintendent'; hired designers or inventors of ever more complicated automatic labour-saving devices; technicians who do nothing but keep the machines in perfect condition. They constitute a new caste that owes its station not to birth or privilege but to sheer ability and opportunity.

Strange to relate, these rulers are themselves ruled by their own inventions. The standardization that they have insisted upon because mass production is impossible without it also restricts them. There is no phonograph monopoly, yet no wide use has yet been made of Poulsen's telegraphone which was invented late in the last century to record a whole opera electromagnetically on a steel wire. The reason? Scores of millions invested in standardized disks on which the music of great artists has been engraved. Monorailway systems have been designed with an astonishing attention to detail, with gyroscopically controlled trains that can make 150 miles an hour on a single rail and dash across an abyss on a steel cable. Have they a chance? Not against a highly standardized railway network which sprawls over a continent, with standardized trains stopping at standardized stations and barely scraping standardized bridges with smokestacks of a standard height.

How many aristocrats of test-tube, electromagnet and gear-wheel are there? No one knows. The total

for the world cannot be more than a million, with perhaps two hundred thousand in the United States. Suppose they were to perish in a night—these million. Back we would slip to the eighteenth century. People in cities would starve to death or die in two weeks of epidemics.

With experts on top of the structure inventing and controlling the mechanism, and, above these, financiers who rule all, what is to become of us? We are brought face to face with the problem of government.

Democracy as we know it is a social and political conception of the eighteenth century. There were no steam-engines, no railway trains, no gas-works, no central stations, no machines to turn out thousands of cigarettes a minute or seal thousands of cans of tomatoes an hour or bend, twist, punch, and squeeze steel for skyscrapers and ocean liners. Liberty, equality, fraternity! They are brave words, words that still thrill men who stand at blast-furnaces or who dip ore out of Great Lake freighters with gigantic electric shovels or feed bars of steel to an 'automatic' which converts them into threaded bolts. Yet there is no denying that as against a ruling military caste of hereditary aristocrats, invention has another ruling caste of technologists and financiers. And the new ruling class is far more powerful than the old. It has had to be curbed by such democratic devices as compensation laws, shorter working-days, unions, interstate commerce and federal trade commissions, public service commissions.

The curbs are the evidences of a deep conviction that the very existence of democracy is at stake. Is it compatible with technoculture? Social problems have become largely technological problems. On the one hand we have democracy trying to settle by popular vote highly intricate problems of finance, taxation, arising out of invention; on the other a colossal mechanism of production, designed and operated by highly competent experts who are guiding our lives. So we ask: are the technical experts to run a whole nation because they happen to run its industrial machinery? Or is the government to run the experts, the inventors, the creators of this evolving culture?

The totalitarian states have made up their minds. Their dictators have decided that the course of scientific research and of invention must be socially directed. The 260 research laboratories of Soviet Russia take their orders from the Academy of Sciences, and the Academy is an integral part of the government. Germany achieves what is possible in economic self-sufficiency by indicating to the university and industrial laboratories exactly what discoveries and inventions are wanted. Mussolini has a national research council which is primarily concerned with Italy's industrial problems. Every totalitarian state plans for the future and holds scientific research to the plan.

To an engineer this is a wholly satisfactory method of dealing with what is called 'the impact of science and invention'. To him there need be no violent,

destructive collision between human rights and methods of production if there is a social plan. Discover human needs, is his formula. List them. Satisfy them with the aid of trained groups of chemists and engineers. Let a highly competent government directorate of scientific research assign the problems to various laboratories. Planning implies strict control. Society must be told what is good for it. Design society as you would a locomotive, and run it as if it were a railway train. Fascism and Communism have both tried to apply the formula.

Planning is distasteful to a democracy. It clashes with individualism, with the egalitarian right of every voter to decide what he wants his government to be and to do. So instead of the clear-cut programme of totalitarian and Communistic states we have much floundering. It is not that democracy is unaware of its danger, but that it does not quite know how it shall deal with the machine and the social problems that it has raised. In President Hoover's time, we had the report of a committee on 'social trends', which discovered that social invention lagged behind technological invention, meaning that some social mechanism must be devised to soften the impact of science and invention. President Roosevelt appointed the National Science Advisory Board, which insisted that we needed new industries to absorb the unemployed and that inventions in the long run always create new industries. It went so far as to indicate what problems should be assigned to research physicists, chemists and

engineers in a systematic effort thus to cope with the economic problems of the depression. We have also had the report on 'technological trends' by the National Resources Committee, an attempt at predicting what Mr H. G. Wells calls 'the shape of things to come' on the theory that if we can foresee that shape we may be able to avert the disastrous consequences of carelessly introducing the formidable inventions that are even now in the making. The prophets who wrote that report argued that it takes from twenty to thirty years for industry to adopt a revolutionary invention —time enough to read the handwriting on the wall, time enough to foresee more obvious social effects, time enough to prepare for the inevitable by formulating adequate legislative and economic policies.

There are manifest impossibilities in thus attempting to predict the shape of things to come and preparing for them. Did Arkwright foresee the slum when he transferred the textile industry to the factory? Or Watt when he converted Newcomen's mine pump into a steam-engine capable of driving other machines? Did Daimler, Duryea and Ford imagine that the automobile would transform rural education, reduce railway dividends to zero, and inspire 500,000 Americans to lead a gipsy life in trailers? Did Whitney know that his cotton-gin would revive a dying slavery and that a civil war would have to be fought to settle some of the issues raised? Or did Otis and his backers realize that his elevator would give us the skyscraper and with it an increase in real-estate values and a problem in trans-

portation whenever a single building discharges on the sidewalk some 50,000 people between five and six o'clock?

Shall it be planned totalitarianism or an adaptable democracy in which social invention rises to meet the human demands of mechanical invention? No one knows. But some form of collectivism is already emerging, simply because mass production, mass entertainment, mass communication, mass appeal, all that we call 'the machine', will have it so. The greatest of all inventions will be the social invention that will make the most of science and technology socially in terms of human happiness.

There are signs enough that democracy can invent socially and save itself from the dictatorial planning of Fascism and Communism. Invention as we see it has grown up in a profit-making society. Whether or not a given machine shall be introduced still depends therefore on its money-making future. No better example can be found than in the electrical industry. Central stations were at first naturally erected in crowded communities where purchasers of energy were huddled together and where it paid to install a complex generating, transmitting and distributing system. But the farmer? He was utterly ignored. Even now he is no better off (except in the irrigated West) than he was in the days of McKinley, so far as electric motors and lights are concerned. There are only three of him to the average rural mile. Unless he pays for the transformers and the distribution system that

makes it possible to reduce to 110 or 115 volts the 100,000-volt current that flows in the high-tension lines strung perhaps across his very land, he must burn kerosene and his wife must do without electric refrigeration and wash clothes by hand.

The Tennessee Valley Authority and similar organizations, so bitterly opposed by public utility companies, must be regarded as quasi-social inventions that set the benefits of electricity above profits. Possibly the avowed object of obtaining yardsticks whereby rates are set will not be attained. But whether or not it is attained there can be no question of the change that will be brought about not so much on the farm itself as in the barnyard and the home. In the days of the old National Electric Light Association the problem was attacked from the viewpoint of deliberately finding profitable new rural uses for electricity, so that enough current would be consumed to justify the erection of poles and distributing apparatus at a cost that the farmer would be willing to pay. Yet the history of all public utilities is a history of services and uses that consumers discovered for themselves. For example, Bell never dreamed that some day a resident of New York would call up his brother in San Francisco to congratulate him on having attained his fiftieth birthday. Nor did Marconi suspect that fishermen would regulate their catches by market demand ascertained by wireless. Nor were the gas companies, which did their best to thwart Edison in his effort to introduce electric lighting, able to see at first that gas would be

used for cooking to the almost complete exclusion of coal in cities. In the end electricity triumphed. It took its place in the community not as a competitor of gas but as a new force of unlimited social potentialities. Now it is recognized that energy is warp and woof of our industrial and domestic life. Without it we would slip back to the early nineteenth century. So powerful an agency cannot be left in the control of profit-making exploiters. The public service commissions may be inefficient, but they testify eloquently enough to the determination of democracy not to be ruled by a class of bankers and engineers who have decided in their own minds where high-tension lines shall be strung and to what regions electric energy shall be distributed.

Even more striking is the social evolution of the railroad. At first the steam locomotive was simply an iron horse that competed with living horses. Then it became a powerful factor in opening up new land in the Middle West and in developing new industrial centres. Its full significance burst upon us during the World War, when it was recognized by the masses for what it was—a colossal transportation-machine sprawling over a continent, linking thousands of towns together. We talked of transportation with a capital T. When the war ended, the question arose whether or not the roads should be returned to private ownership and management. Their subsequent history is probably the eventual history of all public utilities, possibly of all major industries based on great inven-

tions. In other words, transportation, the generation of gas and electricity, the supplying of water to a community, the production of food, clothing, and shelter, can no more be left to private capital than the exploitation of the atmosphere for breathing. We behold the railroads transformed by democracy into real servants of the public. The conditions under which their managers employ labour, the issuance of securities, the rates to be charged for carrying goods and passengers — all are subject to governmental scrutiny and approval. The railway companies are reduced to the status of administrators. They may not even give up an unprofitable branch-line without the government's consent, and, against their will, they must apply the profits earned in crowded communities to the maintenance of transportation in regions where traffic is thin. We have here about the most striking example to be found of democracy's ability to invent to good social purpose and to appraise the social importance of a scientific discovery or invention.

Invention and science are Siamese twins. Sometimes a science develops out of an invention as thermodynamics developed out of research applied to the steam-engine, and sometimes inventions flow from scientific discoveries, as, for example, the generator, telegraph, and the whole apparatus of modern electrical engineering flowed out of Faraday's work in electromagnetic induction. Even under despotism some research, some invention, is possible. But the onward impetus that comes from the slow acceptance

of new theories which may conflict with those generally accepted, ceases. If, for example, the world had not ultimately accepted the Copernican conception of the solar system it would have managed to do its navigation after a fashion in accordance with the Ptolemaic system. But there could have been no Newton, no laws of gravitation, and hence nothing like the mechanical engineering that has given us modern industry.

Now it happens that science stands for something more than coal-tar dyes, electric lamps, X-rays, radioactivity, and monstrous fruit-flies bred by experimental geneticists. It is an attitude of mind, an objective, dispassionate approach to the outer world—what Prof Whitehead calls 'the most intimate change in outlook that the human race has yet encountered'. This attitude, this objectivity, is inconceivable without freedom of thought and freedom of expression. It is no accident, therefore, that science, as we know it, should be an offspring of democracy, no accident that the discoveries of Galileo, Newton, Lavoisier, and others were made during revolutions fomented by liberals.

All this being so—and the case has been convincingly presented by historians of science and political philosophers—the advocates of a society planned from on high, with the necessary suppression of free thought, face a dilemma. They need the scientist. Yet they must deny him the liberty of mind that is the very essence of his objective attitude. If his researches relentlessly expose the fallacy of a fundamental prin-

ciple dinned into the populace by the government, either he must be hanged as a meddler or the social plan must be scrapped. In the modern totalitarian state there is exile or death for the dissenter and not a sign of scrapping.

Clashes of free scientific thought, of scientific objectivity with authority, are familiar enough. They bode no good for research and hence no good for invention. Social planning of the totalitarian, autarchic type, is impossible so long as the scientist is denied the right to think for himself and to carry his thinking into practice.

The votaries of science constitute an international brotherhood the like of which this world has never seen before. It is impossible to say of a discovery or an invention: 'This was the work of a German.' Nor does it matter much to a real scientist or engineer what the nationality of a discoverer or inventor may be. It is enough for him that the man did his work and described it in a readily accessible publication as an addition to the general stock of knowledge. As a force in achieving true internationalism even religion pales in comparison with this subordination of self and country. Despite the secrecy that shrouds military and civil invention, science furnishes the most striking evidence we have that men are able to sink passions for the good of the race.

Hope, then, lies in science. If democracy is to save itself, the scientific outlook, the scientific method of detached appraisal of facts and situations, must become

part and parcel of the common mind. This in turn means that education must be given new purpose, and direction. Or as Wells puts it, the choice is between 'chaos and education'.

There are signs that even without adequate education and the general inculcation of the scientific attitude the masses of democracy are beginning to turn instinctively to the scientist and the engineer. There has been much scoffing at 'brain trusts', but the fact must not be overlooked that, inept as they have been on occasion, they have emerged from the orderly process of democratic government. Their British counterparts are found in royal commissions that patiently examine proposals and decide whether or not they meet the social needs of the hour. It is much that in two great democracies the scientific expert is thus drawn into the government, even though his recommendation may be brushed aside. For all its emotionalism, it is hard to escape the conclusion that the electorate does somehow sense the relationship of science to democracy, that already it dimly recognizes in science the saviour of democracy and the early perceptible beginning of an internationalism that may yet sweep away the artificial barriers that have been raised to check the free intermingling of peoples, goods, and ideas.

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